PB93-102200

Report on the Ecological Risk Assessment Guidelines Strategic Planning Workshop. Held in Miami, Florida on April 30-May 2, 1991

(U.S.) Environmental Protection Agency, Washington, DC

Feb 92

U.S. Department of Commerce
National Technical Information Service

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before comple

1. REPORT NO. EPA/630/R-92/002	3. PB93-102200
4. TITLE AND SUBTITLE Report on the Ecological Risk Assessment Guidelines Strategic Planning Workshop	5. REPORT DATE February 1992
	6. PERFORMING ORGANIZATION CODE EPA/630/R-92/002
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO. RAF 004
9. PERFORMING ORGANIZATION NAME AND ADDRESS US EPA ORD/Risk Assessment Forum (RD-672) 401 M Street, SW Washington, DC 20460	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO. 68-C8/0036
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED Report
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Report on Workshop held on April 30, 1991, to May 2, 1991

16. ABSTRACT

The U.S. Environmental Protection Agency (EPA) is presently developing guidelines for conducting ecological risk assessments. This task is particularly challenging because ecological risks result from exposure of populations, communities, and ecosystems to chemical and non-chemical stressors acting individually or in combination over diverse spatial scales that can include multiple ecosystems. In view of the complex nature of this subject and to provide a basis for planning ecological risk assessment guidelines, the EPA's Risk Assessment Forum convened a scientific workshop at the University of Miami's Rosenstiel School of Marine and Atmospheric Science.

Scientists and experts in ecology and ecological risk assessment from EPA, academia, and other government agencies explored the technical basis for a strategic plan that could be used by the Agency for developing ecological risk assessment guidelines. Topics discussed included: (1) the best scientific approach to organizing ecological risk assessments; (2) the scientific feasibility of implementing ecological risk assessment guidelines for a wide range of stress categories and ecosystems; (3) the scientific issues relative to the risk assessment process; and (4) the subject matter and titles that will constitute the ecological risk assessment guidelines bookshelf.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Release to the public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 73
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

United States
Environmental Protection
Agency

EPA/630/R-92/002
February 1992

PB93-102200

EPA

Report on the Ecological Risk Assessment Guidelines Strategic Planning Workshop

RISK ASSESSMENT FORUM

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA 22161

EPA/630/R-92/002
February 1992

REPORT ON THE ECOLOGICAL RISK ASSESSMENT GUIDELINES STRATEGIC PLANNING WORKSHOP

Risk Assessment Forum
U.S. Environmental Protection Agency
Washington, DC 20460

Printed on Recycled Paper

DISCLAIMER

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

CONTENTS

Acknowledgements vii

Foreward viii

Preface ix

Authors and Contributors x

Executive Summary xi

1. BACKGROUND AND PURPOSE 1

1.1. Background 1
1.2. Purpose 1
1.3. Workshop Organization 2

2. OPENING PRESENTATION 3

2.1. Ecological Risk Assessment: Organizing Principles (Jack Gentile and Mark Harwell, Co-Chairs) 3
2.2. Background 3
2.3. Ecological Principles 3
2.4. Ecological Risk Assessment Variables 4
2.5. Ecological Risk Assessment Landscape - "The Cube" 5

3. WORKSHOP REPORTS ON ECOLOGICAL HIERARCHY 8

3.1. Introduction 8
3.2. Organism-Population Work Group (Steve Bartell, Chair) 8

3.2.1. Policy and Risk Analysis 8
3.2.2. Individuals and Populations 9
3.2.3. Alternatives and Innovations in Population Models 9
3.2.4. Data 11
3.2.5. Extrapolation 11
3.2.6. Miscellaneous 11

3.3. Community Work Group (Ann Bartuska, Chair) 12

3.3.1. Introduction 12
3.3.2. Selection of Stresses 12
3.3.3. Determination of Endpoints 13
3.3.4. Information Needs 14

CONTENTS (cont.)

3.4. Ecosystem Work Group (David Weinstein, Chair) 15

3.4.1. Introduction 15
3.4.2. Criteria for Selecting Endpoints 15
3.4.3. Example Set of Criteria 15
3.4.4. Example List of Endpoints 16
3.4.5. Practical Considerations 18
3.4.6. Issues Requiring Further Consideration 18

4. SCIENTIFIC FEASIBILITY ISSUES 19

4.1. Introduction 19
4.2. Aquatic Ecosystems Work Group (Tom Duke, Chair) 19

4.2.1. Scientific Feasibility Issues 19
4.2.2. Research Needs 23

4.3. Terrestrial Ecosystems Work Group (William Smith, Chair) 24

4.3.1. Introduction 24
4.3.2. Stress Characterization Research Needs 27
4.3.3. Ecological Characterization Research Needs 27

5. SPECIAL TOPICS 28

5.1. Introduction 28
5.2. Stress Characterization Work Group (Robert Huggett, Chair) 28

5.2.1. Introduction 28
5.2.2. Stress Characterization 28
5.2.3. Characteristics of Exposure Assessment 32
5.2.4. Measurement 32
5.2.5. Sources 33
5.2.6. Bioavailability 34
5.2.7. Models 35
5.2.8. Stress Research and Development Needs 35
5.2.9. Summary 36

5.3. Ecosystems Classification Work Group (Richard Wiegert, Chair) 37

5.3.1. Scale-Independent/Qualitative Ecosystem Classification 37

CONTENTS (cont.)

6. ISSUES IN ECOLOGICAL RISK ASSESSMENT 39

6.1. Background 39
6.2. Characteristics of Ecological Risk Assessments 39
6.3. Road Map Work Group (Mark Harwell and Jack Gentile, Co-Chairs) 40

6.3.1. Problem Formulation 42
6.3.2. Response-Recovery Analysis 44
6.3.3. Environmental Decision-Making 46
6.3.4. Relationship to the Ecological Risk Framework 46

6.4. Proposed Future Ecological Risk Assessment Guidelines 47

6.4.1. Background 47
6.4.2. Ecological Risk Assessment Guidelines 49
6.4.3. Ecological Endpoints 49
6.4.4. Ecological Indicators 49
6.4.5. Stress Regime Characterization 50
6.4.6 Ecological Response Characterization 50
6.4.7. Ecological Recovery 50
6.4.8. Environmental Decision-Making 50
6.4.9. Case-Specific Compendium 50

7. REFERENCES 51

APPENDIX A -- AGENDA A-1

APPENDIX B -- LIST OF PARTICIPANTS B-1

APPENDIX C -- LIST OF OBSERVERS C-1

LIST OF FIGURES

Figure 1. Three-Dimensional Matrix of Ecological Risk Organizing Principles 7

Figure 2. Current Strategy for Ecological Risk Assessment: Population Scale 25

Figure 3. Current Strategy for Ecological Risk Assessment: Ecosystem Scale 26

Figure 4. Example Categories of Stressors 30

Figure 5. Scientific Issues in Ecological Risk Assessment 41

Figure 6. Proposed Framework for Ecological Risk Assessment 47

LIST OF TABLES

Table 1. Feasibility Matrix 21

ACKNOWLEGEMENTS

The efforts of all the participants in the workshop that formed the basis for this report are greatly appreciated. In particular, Dr. Mark Harwell and Dr. Jack Gentile provided overall leadership for the workshop, and several other individuals acted as work group chairs, including Dr. Steven Bartell (Organisms-Population), Dr. Ann Bartuska (Community), Dr. Tom Duke (Aquatic Ecosystems), Dr. Robert Huggett (Stress Characterization), Dr. William Smith (Terrestrial Ecosystems), Dr. Richard Weigert (Ecosystems Classification), and Dr. David Weinstein (Ecosystem). Dr. William van der Schalie and Dr. William Wood of the Risk Assessment Forum Staff and Ms. Susan Brager of Eastern Research Group also made significant contributions to the workshop and the workshop report.

FOREWARD

In 1986, the U.S. Environmental Protection Agency (EPA) issued five guidelines for health risk assessment (51 Federal Register 33992-34054, 24 Sept. 1986). Based on a ten-year-long effort, these guidelines set forth risk assessment principles, concepts, and methods for cancer, developmental effects, mutagenic effects, exposure assessment and chemical mixtures. Since then, EPA has developed guidance in other health risk areas, with the result that a total of nine guidelines for health risk assessment are available or under development. Despite controversies in some areas, each of the guidelines has been well received and is widely used.

For several years, responding to requests from EPA scientists and from the public, EPA has been weighing approaches to comparable guidance for ecological effects. In 1990, the Risk Assessment Forum, which is responsible for EPA's Agency-wide risk assessment guidance, initiated three ecological risk guidance projects: (1) a set of case studies to illustrate the "state-of-the-practice" in ecological assessments; (2) a "framework" to describe the basic principles for ecological risk assessment; and (3) a long-range plan for developing specific ecological risk guidelines, which was the topic for a workshop held in Miami, Florida in April 1991.

The Miami Workshop was an important event for the Risk Assessment Forum. It was the first step in a multi-year program to develop detailed guidelines for ecological risk assessment. In essence, EPA was seeking to identify and define the ecological effects counterparts to the existing EPA guidelines for health risk assessment.

EPA did not expect to develop substantive guidance during this workshop; nor did EPA expect to address or resolve all of the many issues that impact an activity of this kind. Rather, EPA asked experts on ecology, ecotoxicology, and ecological risk to identify topical areas and define the general scope for EPA's first ecological risk assessment guidelines through consideration of organizing principles and scientific feasibility issues. This workshop report contributes to EPA's long-term plan for the development of ecological risk assessment guidelines along with two other reports that discuss a framework for conducting ecological risk assessments (U.S. EPA, in press-a; U.S. EPA in press-b).

Dorothy E. Patton, Ph.D.
Chair
Risk Assessment Forum

PREFACE

On April 30, 1991, EPA convened a workshop to assist in developing guidelines for improving ecological risk assessment (56 Federal Register 16333, 22 April 1991). Dr. Mark Harwell and Dr. John Gentile chaired the three-day meeting, which was held at the University of Miami School of Marine and Atmospheric Science. Participants included experts on ecology, ecotoxicology, and ecological risk assessment from universities, EPA, other Federal agencies, and private organizations.

The Miami Workshop was the first of several workshops held during the spring of 1991 as part of a new EPA program to develop guidelines for ecological risk assessment. Each workshop was designed to open a dialogue among experts on issues pertaining to the development of such guidance. This workshop report highlights issues and recommendations developed at the Miami Workshop.

AUTHORS AND CONTRIBUTORS

EPA's Risk Assessment Forum sponsored a 3-day workshop on April 30 to May 2, 1991, at the Rosenstiel School of Marine and Atmospheric Science at the University of Miami to examine the technical basis for developing a strategic plan for future ecological risk assessment guidelines. Risk Assessment Forum Staff provided overall guidance for this workshop. Appreciation is extended to the University of Miami for hosting this workshop and to Christine Harwell and Melanie Bethel for onsite support. Eastern Research Group, Inc. (EPA Contract No. 68-C1-0030) handled logistics for participants and provided assistance for this report.

Authors

John H. Gentile (Co-Chair)
U.S. Environmental Protection Agency
Environmental Research Laboratory
Narragansett, RI

Mark A. Harwell (Co-Chair)
University of Miami
Miami, FL

Contributors

Steven Bartell (Chair, Population Work Group)
Oak Ridge National Laboratory
Oak Ridge, TN

Ann Bartuska (Chair, Community Work Group)
USDA Forest Service
Washington, DC

Thomas Duke (Chair, Aquatic Work Group)
Technical Resources Institute
Gulf Breeze, FL

Robert Huggett (Chair, Stress Characterization Work Group)
College of William and Mary
Gloucester Point, VA

William Smith (Chair, Terrestrial Work Group)
Yale University
New Haven, CT

David Weinstein (Chair, Ecosystem Work Group)
Boyce Thompson Institute
Ithaca, NY

Richard Weigert (Chair, Ecosystem Classification Work Group)
University of Georgia
Athens, GA

EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) is developing guidelines for conducting ecological risk assessments. This task is particularly challenging because ecological risks result from exposure of populations, communities, and ecosystems to chemical and nonchemical stressors acting individually or in combination over diverse spatial scales that can include multiple ecosystem types. In view of the complex nature of this subject, and to provide a basis for planning ecological risk assessment guidelines, EPA's Risk Assessment Forum convened a scientific workshop at the University of Miami's Rosenstiel School of Marine and Atmospheric Science.

Scientists with expertise in ecology and ecological risk assessment from EPA, academia, and other government agencies explored the technical bases for a strategic plan that could be used by EPA for developing ecological risk assessment guidelines. Topics discussed included: (1) the optimal scientific approach to organizing ecological risk assessments, (2) the scientific feasibility of implementing ecological risk assessment guidelines for a wide range of stress categories and ecosystems, (3) the scientific issues relative to the risk assessment process, and (4) the subject matter and titles that will constitute the ecological risk assessment guidelines bookshelf. The major points from these discussions are summarized below.

- Organizing Variables. In a preworkshop paper, the following five variables were proposed as the basis for organizing ecological risk assessments: ecosystem type, stress type, spatial scale, temporal scale, and level of biological organization. These five elements, which circumscribe the boundaries within which ecological risks occur, represent the foundation for the ecological risk assessment process that will form the basis for future guidelines. Each variable was discussed within the context of its applicability to the risk assessment process. Scale, be it spatial, temporal, or level of biological organization, is an important component of the ecological risk assessment process to be addressed in future guidance. While current concepts of stress characterization and exposure are most relevant to chemical stresses, future guidelines must address the emerging importance of anthropogenic nonchemical stresses (e.g., global climate change, stratospheric ozone depletion, habitat destruction or alteration, and species depletion) (U.S. EPA, 1990). The traditional structural classification of ecosystems (e.g., deciduous forests, freshwater wetlands) should be supplemented with functional properties (e.g., energy and nutrient cycling, decomposition) to facilitate the coupling of stress modes of action to the nature of the ecological response and recovery. Finally, guidance will be needed to ensure that the magnitude and extent of the stress, the spatial and temporal scales, and the level of biological organization used in the risk assessment are compatible.

- Feasibility. The scientific feasibility of addressing ecological risk assessments was examined from the perspective of both current knowledge and additional research that will need to be conducted. Feasibility was based upon the adequacy of ecological theory, models, and methods needed for making assessments at various levels of biological organization. The following general observations emerged from the discussions. Although an extensive body of ecological theory is available at all levels of biological organization, its application to ecological risk is most well developed at the organism and population levels of organization, primarily because of the historical focus on chemical contamination. In general, the availability and applicability of

ecological theory and models decreases when the scale of the risk assessment (i.e., temporal, spatial, and biological) increases and when there is more than one stress operating simultaneously. Consequently, nonchemical and multiple stresses coupled with regional or global spatial scales present serious challenges to our current scientific understanding and capabilities and will require additional research before guidance can be provided.

- Scientific Issues in Ecological Risk Assessments. The workshop examined a spectrum of scientific issues associated with the ecological risk assessment process. This included the full range and complexity of stress and ecological response issues, rather than trying to adapt risk assessment approaches developed for non-ecological problems. The result was a description of the process and associated scientific issues that should be addressed in ecological risk assessment guidelines. The following issues were highlighted:

  (1) it must be recognized that the stress-characterization process proceeds in parallel with ecological-effects characterization, with inputs and feedbacks occurring at several stages;

  (2) guidance is needed for identifying the specific ecosystem(s) at risk and selecting the appropriate ecological endpoints of concern;

  (3) the actual characterization of ecological risks results from integrating the full range of stress-response and recovery relationships, produced from both qualitative and/or quantitative methodologies; and

  (4) guidance and dialog on interfacing the risk assessment process with "environmental decision-making" (risk management) are needed.

- The Guidelines Bookshelf. Because of the complexity of the ecological risk assessment process, a single guidance document is not feasible. Rather, workshop participants proposed a Bookshelf that will contain both guidelines and supplemental resource volumes. The foundation for future guidelines subject matter emerged from the description of the ecological risk assessment process and related scientific issues. The initial volume, the "Ecological Risk Assessment Guidelines", could provide comprehensive guidance for conducting ecological risk assessments. This volume would expand and provide greater detail on the risk assessment principles described in EPA's "Framework for Ecological Risk Assessment" (U.S. EPA, in press-b), provide criteria for selection of ecological endpoints, and provide scientific consensus on issues critical to the conduct of ecological risk assessments. In addition, these guidelines could include selected examples to illustrate the conduct of ecological risk assessments for specific ecosystems and particular stresses. Simultaneously, other companion volumes could be developed to provide detailed information on important components of the risk assessment process. For example, volumes could be prepared for: (1) selecting ecological endpoints and indicators, (2) stress characterization, (3) risk characterization, (4) ecological effects and recovery, and (5) environmental decision-making. These volumes would supplement the guidelines and provide the detail necessary for determining the risks for various stressors and ecosystems. The final

volume on the bookshelf could be a compendium of case studies developed from the application of the guidelines to a wide range of problem-oriented situations.

1. BACKGROUND AND PURPOSE

1.1. Background

EPA's risk assessment program historically has focused on developing guidelines for assessing chemically induced risks to human health (U.S. EPA, 1986). EPA's extensive experience with specific risk issues in human health has provided a sound basis for defining the scope, principles, and subject matter for human health risk assessment guidelines. The subject, that is the endpoints for human health risk assessment, resulted from extensive discussions during a period of several years prior to the development of human health guidelines. In addition, the endpoints, such as carcinogenicity and developmental toxicology, were of recognized public health and regulatory importance. Similar discussions regarding the selection of endpoints for ecological risk assessment have begun only recently and are confounded by the lack of specific legislative and regulatory guidance. Another important factor in human health risk assessment is the focus on estimating the risks to a single species, humans. Finally, human health assessments have traditionally assessed the risks from radiological and chemical stresses.

Although there are similarities to human health risk assessments, ecological risk assessments must consider exposure of populations, communities, and ecosystems to chemical and nonchemical stresses acting individually or in combination over diverse spatial scales that can include multiple ecosystem types (Barnthouse and Suter, 1986; U.S. EPA, 1988; Harwell et al., 1990). The scale and complexity of ecological systems and their interactions with anthropogenic and natural stresses present a challenge to preparing guidelines that can be used for assessing risks and recovery in these ecosystems.

EPA, through its Risk Assessment Forum, is developing a set of guidelines for conducting ecological risk assessments. It is anticipated that the guidelines will be used by EPA in conducting ecological risk assessments and will likely be the basis for assessments conducted by other organizations. Three activities are presently under way: (1) preparation of a framework document that provides the basic philosophy and conceptual basis for ecological risk assessments; (2) preparation of a case studies volume that illustrates how ecological risks are presently assessed; and (3) preparation of a long-range plan for developing future ecological risk assessment guidelines.

1.2. Purpose

The purpose of the strategic planning workshop was to provide EPA with recommendations on the subject matter and feasibility of ecological risk assessment guidelines to be developed over the next several years. A 3-day workshop was convened on April 30, 1991, at the Rosenstiel School of Marine and Atmospheric Science (RSMAS) at the University of Miami to examine the technical basis for developing a strategic plan for future ecological risk assessment guidelines (56 Federal Register 16333, 22 April 1991). Approximately 35 scientists from academia, EPA, and other Federal agencies participated in a series of work groups addressing various aspects of ecological risk assessment. The goal of the workshop was first to identify the organizing variables that could be used to circumscribe the spectrum of potential types of ecological risks for which guidance would be needed. Then, through a review of scientific principles and feasibility, the workshop participants would aggregate these potential options into a limited number of subject-specific candidate guidelines.

1.3. Workshop Organization

The workshop opened with a presentation on ecological principles that described the major elements in ecological risk assessment and was followed by a series of work group discussions that expanded upon these principles in several different ways. This report reflects the discussions within each work group and presents the scientific perspectives on ecological risk assessment and associated guidelines that emerged from the discussions at the Miami workshop.

The first set of work groups reviewed the theoretical basis for ecological risk assessment, addressing levels of ecological organization, types of ecosystems, categories of anthropogenic stresses, and fundamentals of stress ecology. A second set of work groups examined pragmatic issues of ecological risk assessment, i.e., what is feasible at present, what may be feasible after a few years of research and development, and what is not feasible without considerable additional research and improved understanding. These work groups examined different categories of ecosystems with respect to the availability of laboratory and field data bases, availability of models and other analytical methodologies, and knowledge of how ecosystems respond to stress. Finally, a third set of work groups examined: (1) alternative ways to classify ecosystems; (2) issues of stress characterization; and (3) processes for conducting ecological risk assessments, particularly as they relate to defining the subject and content of future guidelines.

This workshop report begins with a discussion of organizing principles for ecological risk assessment and describes how these principles are combined to delineate the boundaries within which ecological risks occur and are assessed (section 2). This section is followed by three work group reports, each examining a different level of ecological organization (section 3). Section 4 examines the availability of analytical models and suitable data bases for aquatic and terrestrial systems and addresses the feasibility of conducting ecological risk assessments. Section 5 addresses special topics on stress and ecosystem classification. Section 6 provides a detailed description of the scientific elements and issues pertinent to ecological risk assessment and illustrates the flow and integration of information on stress and ecological effects required to evaluate risk. This section concludes with recommendations on potential subject areas for future ecological risk assessment guidelines.

2. OPENING PRESENTATION

2.1. Ecological Risk Assessment: Organizing Principles (Jack Gentile and Mark Harwell, Co-Chairs)

2.2. Background

The first task of the workshop was to define the scope and subject matter of ecological risk assessment guidelines. The ecological risk assessment guidelines should have the breadth and flexibility to address a wide range of environmental risks resulting from individual and multiple chemicals acting singly or in combination and from nonchemical stresses that occur over a wide range of spatial, temporal, and biological scales. Consequently, the subject matter for the ecological risk assessment guidelines was not predetermined. In contrast, the subject matter of the human health guidelines was defined through extensive experience. The purpose of these initial workshop discussions was to focus on the selection of organizing principles that have a strong scientific basis, capture the essential features of the ecological risk assessment process, and that could be used to delineate options for selecting the subject matter of future ecological risk assessment guidelines.

Three sources of information were used to identify the organizing principles: (1) knowledge and understanding of the principles of stress ecology, (2) knowledge of the risk assessment process, and (3) information on current and emerging environmental problems. For example, recent studies suggest that the scale of environmental problems continues to increase from local to regional to global and that nonchemical stresses are becoming increasingly important (U.S. EPA, 1990). This information helps EPA decision-makers decide which problems are most important and where to focus limited resources. This information also can be used to delineate the scope and relative importance of scientific issues that need to be addressed in the guidelines development process.

2.3. Ecological Principles

Understanding the scope and factors that need to be considered in developing guidance for ecological risk assessments requires knowledge of both the stress and the ecological system being affected. Central to understanding the roles and interactions of a stress in ecological risk assessment is knowledge of the stress regime experienced by various components of the ecosystems, how ecosystems respond to stresses, and how ecosystems recover from or adapt to stress (Kelly and Harwell, 1989; Kelly and Harwell, 1990).

Difficulties in predicting ecological responses and recovery from anthropogenic disturbances derive from several factors. First, there are a wide array of types of ecosystems that are of concern to humans. Second, unlike the human organism, which is tightly organized and highly homeostatic, ecosystems are only loosely interconnected, with many different mechanisms for positive and negative feedbacks and relatively low levels of homeostasis. Third, there is no universal, simple measure (endpoint) of ecological health that is analogous to those measures used in human health risk assessment.

Consequently, the workshop identified the need for criteria and guidance for selecting endpoints for ecological risk assessments. Because of the complexity of ecosystems and their interactions with natural and anthropogenic stresses, "ecological endpoints", that is those characteristics

of ecosystems that are directly or indirectly important to the ecosystem and/or to humans, probably will have to be identified on a stress- and ecosystem-specific basis.

Assessing the interactions of internally complex ecosystems of various types with individual and multiple anthropogenic and natural stresses requires an understanding of the following important issues:

- the spatial and temporal scales of the stress;
- differential intensity of stress across various components of the ecosystem;
- interactions among anthropogenic stresses and between natural and human-induced stresses;
- natural variability and the problems of discriminating an anthropogenic stress from background noise; and
- the different modes of action of the stress on the ecosystem.

Consequently, the possible stress-response relationships are quite diverse, are ecosystem- and stress-specific, may involve a diverse set of ecological endpoints, and may include nonlinearities and thresholds. Ecological recovery from mitigated or eliminated stress likewise involves multiple scales of hierarchy, time, space, and is stress- and ecosystem-specific. Substantial uncertainties exist in predicting stress-response and recovery relationships, some of which may be reduced through further ecological research in the laboratory and the field or through improved model development. However, because certain aspects of environmental uncertainty are intrinsically irreducible (e.g., natural variability in weather or other physical conditions), environmental decision-making always must proceed in the presence of uncertainties.

These principles illustrate the scope and diversity of issues that influence attempts to provide specific predictions of an ecosystem's response to a stress. Recognizing that there are considerable complexities and uncertainties should not preclude using expert scientific judgment to separate the general relationships or principles useful for ecological risk assessment from the seemingly infinite array of individual circumstances and uncertainties of ecosystems.

2.4. Ecological Risk Assessment Variables

The first step in the ecological risk assessment process is to identify the organizing variables that circumscribe the potential landscape within which ecological risk assessments are defined and conducted. It is clear from the foregoing discussion and other scientific evidence (U.S. EPA, 1990) that stress, ecosystem type, level of ecological organization, spatial scale, and temporal scale are the primary organizing variables in the ecological risk assessment process. Furthermore, "scale" (temporal, spatial, and biological) is one of the factors distinguishing ecological risk from human health risk and is a major source of uncertainty in ecological risk assessments.

Together, the following five variables can be used to bound the ecological risk assessment landscape and capture the essential features of the risk assessment process. Each category can be further subdivided as desired, to reflect specific attributes of scale, organization, or stresses.

- Stress. The type, properties, temporal and spatial patterns, and interactions of the stress are of fundamental importance in defining the temporal and spatial dimensions and the potential types of ecological effects of the risk assessment.

- Ecological Organization. Ecological organization reprsents the level of biological complexity (for both ecological endpoints and indicators) at which the ecological risk assessment is conducted. In theory, the scale of ecological organization chosen for the ecological risk assessment is dependent upon both the spatial and temporal scales of the stress and the co-occurring ecosystem components affected by the stress.

- Ecosystem Type. Ecological assessments are currently ecosystem-specific; that is, assessments describe the risk of ecological effects for aquatic, terrestrial, or wetlands categories of ecosystems and/or their respective subcategories. This type of classification assumes that the stresses and the ecological effects do not interact and that risks, therefore, can be segregated among ecosystem types.

- Spatial Scale. Spatial scale delineates the area over which the stress is operative and within which direct ecological effects may occur. Indirect ecological effects may greatly expand the spatial scale required for the assessment.

- Temporal Scale. Temporal scale defines the expected duration for the stress, the time-scale for expression of direct and indirect ecological effects, and the time for the ecosystem to recover once the stress is removed.

These variables represent explicitly or implicitly the primary categories of information that are required for developing the "universe" of potential ecological risk assessment guidelines options.

2.5. Ecological Risk Assessment Landscape -- "The Cube"

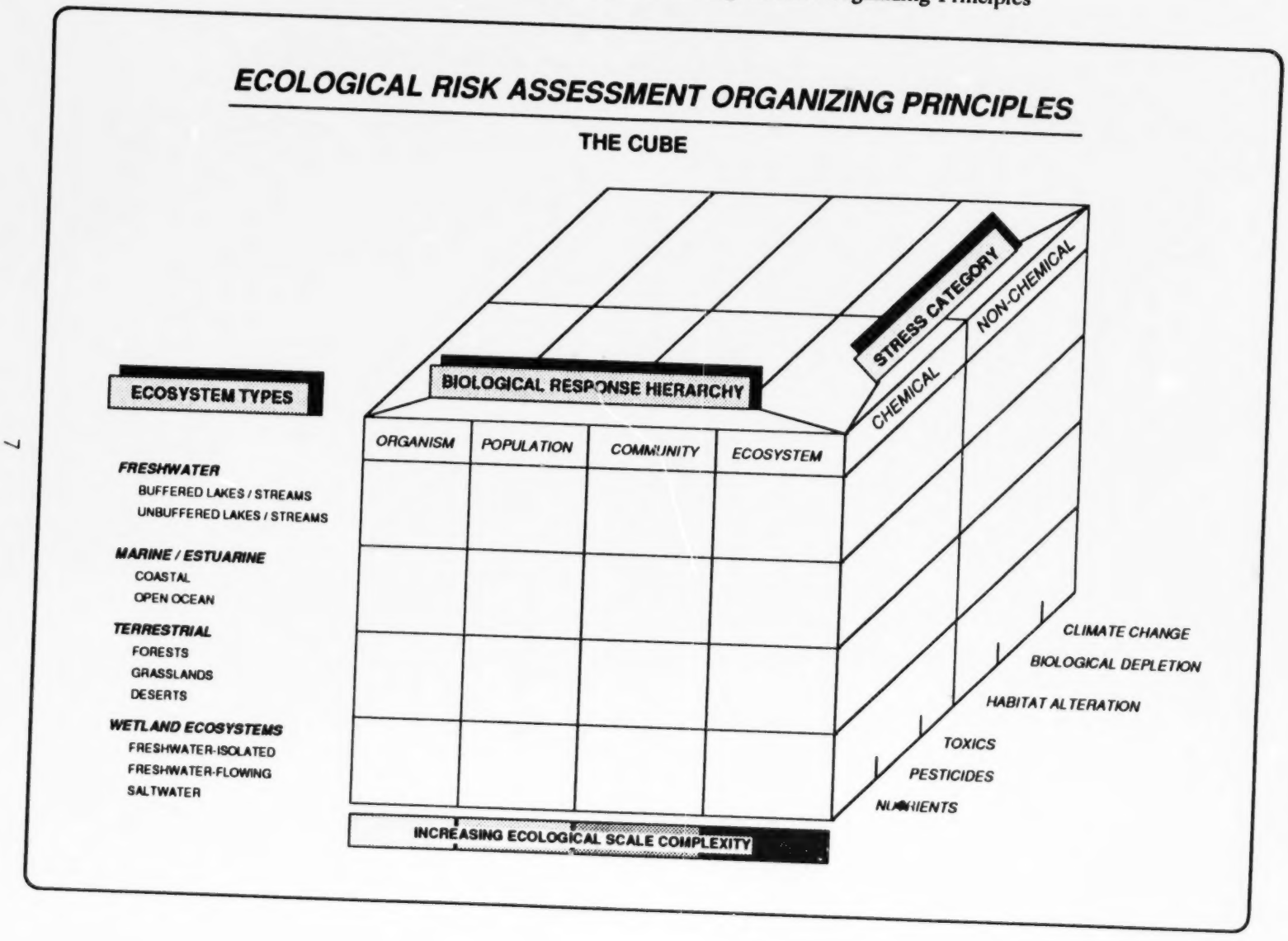
Having proposed a suite of variables that are necessary for defining the subject matter and content of ecological risk assessment guidelines, the next step was to examine various options for combining variables. For example, the guidelines could be organized around stress and ecological hierarchy, stress and ecosystem type, ecosystem type and ecological hierarchy, etc. The challenge was to optimize the integration of the variables into one or more satisfactory configurations that capture the scientific issues central to the risk assessment process.

The option presented and adopted at the workshop describes the scope of the ecological risk assessment process as a three-dimensional matrix--"The Cube." This matrix recognizes the importance of levels of ecological organization, stress type, and ecosystem type as the primary variables in the risk assessment process (figure 1). The three-dimensional matrix illustrates the role of stress in defining both the spatial dimensions of the problem and the ecosystem(s) at risk and the dependency among the stress type, properties, mode of action, and the responses of ecological endpoints.

The scale and resolution of this matrix are particularly useful for ranking the relevancy and importance of specific combinations of variables, for identifying scientific issues, and for determining the state-of-the-science and feasibility of conducting risk assessments using each of these axes. One of the goals of the Miami workshop was to evaluate the contribution of each of these organizing variables to the risk assessment process. Since the biological response hierarchy axis is the source of the

endpoints used in ecological risk assessments, the first task of the workshop was to evaluate both the theory and feasibility of making assessments at the organism, population, community, and ecosystem levels of ecological organization.

Figure 1. Three-Dimensional Matrix of Ecological Risk Organizing Principles



3. WORKSHOP REPORTS ON ECOLOGICAL HIERARCHY

3.1. Introduction

Ecological hierarchy or level of ecological organization is one of the critical organizing principles identified in the risk assessment process. Biological responses from one or more levels of organization are used to assess ecological risks from both chemical and nonchemical stresses. To examine this important principle, the workshop participants were divided into three work groups representing the scales of ecological organization commonly used in ecological assessments: organism-population, community, and ecosystem. The chairperson for each work group presented a discussion initiation paper on the principles for each level of biological scale that are both generally accepted within the scientific community and essential to the risk assessment process as conducted in various ecosystem categories (e.g., aquatic, terrestrial).

Topics discussed in each work group included: (1) determining the scientific feasibility and appropriateness of using each level of organization for assessing ecological risk as a function of spatial and temporal scale, category of stress, and ecosystem type; (2) identifying scientific issues that are critical to the risk assessment process but that exceed the current state-of-the-science; and (3) determining the critical information gaps and research needs to be addressed.

While it is clear that resolution of these and other issues may have been beyond the scope of this workshop, it was important that the critical issues be identified and accompanied with a statement on the state-of-the-science. The perspective on feasibility that emerges can be used by EPA in developing its ecological risk assessment guidelines strategy. The following section presents summary reports from each work group chairperson.

3.2. Organism-Population Work Group (Steve Bartell, Chair)

3.2.1. Policy and Risk Analysis

Under the standard paradigm of risk assessment, regardless of the level of biological organization, the process of risk assessment consists of several components: (1) the potentially hazardous nature of the stress must be determined; (2) the degree of exposure to the stress must be quantified (for toxic chemicals, the exposure must be translated into an estimate of dose to some ecological target); and (3) dose must be translated into an estimate of risk for a corresponding ecological endpoint.

The component processes of ecological risk closely parallel the process of human health risk analysis. The development of credible methods for ecological risk analysis should not, however, be constrained by the human health paradigm. Interestingly, the acceptable levels of risk for humans appear to have been derived from social and economic reasons, not for the implications of human survivorship or the population dynamics of humans. This contrasts with ecological risk analysis, where levels of risk are assessed in the context of overall population dynamics for the target organisms.

The work group members were generally in agreement that methods for estimating ecological risk to populations (and other hierarchical levels) cannot be developed independently of the policy

objectives of regulation. Precisely formulated regulatory objectives are required to facilitate the design of effective methods for estimating ecological risks in relation to EPA needs.

Currently, EPA uses ecological risk analysis to address different regulatory, policy, or legislative demands. For example, the regulation of pesticides requires analysis of chemicals designed to be toxic to specific populations. In contrast, under the Toxic Substances Control Act, risk analysis is used to estimate the potential toxicity of new industrial chemicals. Within Superfund, ecological risk analysis attempts to quantify the reductions in risk to populations in relation to alternative remediation plans for hazardous waste sites.

To design useful and effective methods for population-level risk analysis, the technical community should be involved with EPA policy- and decision-makers from the outset. This feedback loop will help ensure that policy and regulatory needs are understood by the methods developers. In turn, the methods developers can provide technical information in the most useful format and assist the policymakers and regulators in understanding the ecological implications of their decisions. Policy, regulations, and decisions are, after all, uncontrolled experiments. Monitoring the results of these decisions can provide information for evaluating and refining methods and future decisions.

3.2.2. Individuals and Populations

The work group recognized the important point that population-level effects really reflect the aggregate response of individual organisms. That is, exposure occurs at the level of the individual, and individuals respond to stress. In this sense, it can be argued that the fundamental unit of ecological risk analysis is the individual. Not all work group members, however, agreed; it also can be argued that the population is the fundamental unit for risk analysis. One advantage is that ecological risk methods aimed at the individual can take advantage of decades of detailed life-history data, life tables, behavior information, etc. Summarizing individual responses at the level of the population permits the development of risk methods in terms of classic demographic models, including estimates of stress effects on natality, mortality, net reproductive potential, and other traditional demographic descriptors.

3.2.3. Alternatives and Innovations in Population Models

There are at least four population modeling approaches that could contribute to the development of credible methods for ecological risk assessment. The following approaches are in various stages of development:

- Stable Population Theory. The theory of stable populations has produced the life-table approaches and analyses employed traditionally to characterize population fluctuations. Rates of increase, population structure (e.g., age, size, physiological condition), reproductive value, and the sensitivities of these parameters have been thoroughly examined and appear directly applicable to ecological risk assessment. The primary drawback may be in the general availability of data. Nevertheless, the theory is sufficiently advanced to the point of identifying the necessary measurements.

- Equilibrium Population Theory. The theory of equilibrium populations has similarly produced models that have been fairly well studied. These models formulate changes in population structure and abundance that may be applicable to ecological risk estimation.

- Stochastic Population Theory. The theory of stochastic populations can contribute additional endpoints for risk analysis. Stochastic growth rates, population variability, and probabilities of extinction are important components of stochastic theory. This body of theory and the associated models, data collection methods, and analysis have been less well developed. Stochastic population theory and methods may be sufficiently developed for ecological risk assessment in 5 to 10 years.

- Individual-Based Population Models. Individual-based population models that explicitly represent individual organisms have been developed to describe population dynamics. These models offer the advantage of integrating life-history information, demographics, behavior, and bioenergetics in algorithms that have been impossible or extremely difficult to represent using traditional modeling approaches. These models are largely in the exploratory stages; problems remain in terms of conceptualization, parameter estimation, and computational demands. One work group member indicated from experience with these kinds of models that the necessary detailed biological information will seldom be available for species of interest. It is quite likely that the computational constraints will relax before the data limitations decrease.

There remains much to be explored in the application of deterministic and stochastic population models to ecological risk estimation. This also applies to continuous versus discrete population models. For example, if organisms are modeled as discrete entities in continuous time, one set of equations applies, and these equations are fairly well understood. If continuous rates are expressed in discrete time, however, another set of equations describes the population, but these equations are less well understood.

Accurate population forecasting based on process-level understanding will require a long-term EPA investment. The three previously listed theories primarily project population change in relation to current population structure. While it is possible to some degree to forecast from purely an empirical approach (e.g., time-series analysis), true forecasting remains a challenging area for development, both in theory and methods. Time-series methods remain limited by insufficient data for nearly all populations of interest.

Between the aggregate demographic models and the detailed individual-based models lies an intermediate level of population description. Special partial differential equations (e.g., von Foerster equations) permit the simultaneous consideration of disparately scaled biological phenomena (e.g., feeding events over seconds or minutes, individual growth over days). The mathematical properties of these equations are quite distinct from the classical demographic equations. The meaning of these differences for ecological risk analysis should be explored.

3.2.4. Data

The work group had several observations on the nature of data for use in estimating ecological risks at the population level. One question that needs answering concerns the criteria for selecting populations that are of interest in ecological risk analysis. Raptors, including the spotted owl and the bald eagle, are easily justified choices in relation to concerns over habitat loss and pesticides. By contrast, the tri-butyl tin (TBT) issue was decided in relation to a little-known population of mussels; the case against TBT was simplified by a readily available, less toxic alternative. The "so-what" question regarding population effects needs a consistent framework for assessment.

Concern was expressed that useful information produced by routine toxicity testing is not commonly reported. The raw data and exposure-response curves for chemicals should be accessible in addition to the routinely calculated toxicity benchmarks. More emphasis should be placed on chronic testing. It also was noted that much information of potential value is simply not collected during sample processing (e.g., length-weight data, histopathological data, condition). Data that might be useful for extrapolating individual responses to populations or from laboratory to field are simply not collected. Concern also was expressed that if individual organisms are collected and measured, a sufficient sample of different ages, sizes, and sexes must be obtained in order to characterize accurately the population, either in laboratory or field collections. Importantly, if population models are to be implemented for estimating ecological risk, data and assays must be designed or modified to provide the necessary input information. This information is particularly critical if the full potential of individual-based models is to be realized. More detailed information at the individual level is needed.

3.2.5. Extrapolation

The work group recognized the need for extensive and continued efforts in addressing the ability to extrapolate laboratory-measured toxicity to the field. There was consensus that resources need to be committed to collection of additional field data. These data will be used to establish rules for extrapolation, as well as for testing current population models, which the work group realized represents a potential long-term EPA commitment. It was suggested that the EPA Environmental Monitoring and Assessment Program (EMAP) might be involved in collecting some of the necessary field data.

Interestingly, several work group members expressed the opinion that our ability to extrapolate is better than generally believed and that accurate estimates of exposure concentrations are the key to successful extrapolations. The distinction between exposure and dose is also important; one current drawback of routine toxicity tests is that exposure is calculated, not measured, and dose is not measured. As a result, no relationship between exposure and dose is established.

3.2.6. Miscellaneous

Experimental approaches to estimating ecological risk, even at the population level, remain logistically prohibitive especially if a set of multiple stresses and potential target populations is considered. The combinations and permutations escalate at a rate that removes experimental approaches from serious consideration. The work group reserved some hope that the effects of multiple stresses might be addressed through detailed study of the underlying mechanisms of exposure and toxicity of individual stresses acting independently.

Emphasis has been placed on structural entities for ecological risk analysis. Work group members pointed out that it also is possible to emphasize processes. That is, populations represent an integration of underlying birth, growth, and death processes, so why not focus directly on the underlying dynamics as endpoints in risk analysis? It is possible to view populations in terms of potential and to estimate the effects of stresses on the realization or altering of that potential. This shift in emphasis from structure to function might stimulate the development of new models and assays for use in ecological risk assessment.

The issue of biomarkers was raised. There was consensus that these relatively new measures might provide useful information regarding the exposure of individuals to stress. Much work remains in understanding the implications of biomarkers for toxic effects at the level of the individual and the population.

3.3. Community Work Group (Ann Bartuska, Chair)

3.3.1. Introduction

The charge for the Ecological Community-Level work group was to identify the endpoints, or community characteristics of interest, when considering the risk of any ecosystem to any stress. The work group was adamant and unanimous in its opinion that the "community" could not be separated from either populations or ecosystems, because of the numerous interconnections and dependencies across the levels. Rather, the work group recommends that "critical endpoints" be identified, and that the nature of the endpoint (e.g., maintenance of species diversity) be determined at whichever level in the biological hierarchy information is gathered and analyses are conducted.

A second overlying issue was generated by the question--how is an endpoint selected? If ultimately we want to provide some prediction of change from the intersection of stress "x" with ecological endpoint "y," guidelines must be developed to determine the importance of change. Importance in ecological terms is one approach, but equally important is the recognition of human values and management goals in the decision-making process.

3.3.2. Selection of Stresses

In attempting to begin selection of endpoints, we kept coming back to the question, with respect to which stress? The work group reviewed the proposed list of stresses and determined that there are additional possible stresses that should be considered. The following list of stresses has been stratified by spatial scale, although some factors are effective at more than one level. The list may not be complete and can be modified based on the input from other groups.

1. Local Scale

- organic additions--related to aquatic systems;
- thermal pollution--specifically effluent discharges;
- electromagnetic (ionizing radiation);
- habitat alterations and sedimentation;
- eutrophication;
- toxic effects; and
- ozone additions (tropospheric).

2. Regional Scale

- acidic deposition;
- ozone addition (tropospheric);
- toxic effects;
- species depletion or removal; and
- management activities and habitat alteration.

3. Global Scale

- ozone depletion (stratospheric); and
- global warming or cooling.

As a final comment, the work group indicated that in many cases stresses do not occur in isolation. It is essential that stress co-occurrence and interactions be acknowledged and assessed together.

3.3.3. Determination of Endpoints

Within the workshop guidelines, this work group focused on the community level of organization, determining that communities will operationally be handled as the interaction of populations. The overall or umbrella endpoint, therefore, became "sustainability of community structure." The primary measurement endpoints are: number of species, abundance, and frequency. No "value" was put on the number of species, that is, determining if endemic or introduced. This is an issue that may need to be incorporated into the ecological risk assessment process. Some stresses may create new habitats that can increase the number of species and presumably diversity. The value of such a change across the landscape is important to consider. These measures should be evaluated within the more complex endpoints of:

- diversity;
- competition--or more specifically, such issues as competitive release;
- food-web analysis;
- sensitivity of keystone species to the stress;
- minimum number of species and their distribution to maintain a community (this community endpoint also should be extended as a concept to the landscape, along with number and distribution of species/communities to sustain an ecosystem); and
- productivity.

While the relative importance of each of these ecological endpoints may vary depending on the ecosystem of concern, the work group felt that all endpoints should be evaluated in an ecological risk assessment.

3.3.4. Information Needs

Within the ecological risk assessment process there will be a gathering of knowledge and, perhaps more importantly, the identification of knowledge gaps. The information needs discussed below reflect a hierarchy of short-term activities--things we can do now--and longer term research efforts. The importance of the latter is in the refinement of a data base in order to reduce uncertainty. (The following list does not necessarily reflect priorities, nor any particular sequence of events.)

- Develop expert judgment/assessment on risk impact. This process would allow an *a priori* description of what we know, and from this we could identify what we need to know at the stress-endpoint intersection.

- Develop model(s) to be used to assess impact of all stresses. These could be simple models designed primarily for conceptualization and to identify information needs. The models should be developed for a set of ecosystems selected for their value.

- Monitor to characterize the way the community is structured now, using the selected endpoints, and to identify changes at the community level.

- Conduct exposure monitoring and characterization for each stress. It is especially important that this information be linked to the field (i.e., "real-world" conditions) and not theoretical conditions.

- Perform fundamental work to describe the mechanisms of competition.

- Develop a fundamental understanding of food-web structure.

- Conduct cause-and-effect experimentation, coupling laboratory/greenhouse results with the field.

Several of the above-mentioned needs can be accomplished in reasonably short timeframes, and actually may be only a focused compilation of readily available data. For others, some data can be used in the risk assessment process now, but with a wide range of uncertainties. As new studies are completed, the uncertainties may be reduced. Therefore, the ecological risk assessment process should be able to adapt to the accumulation of new knowledge through continuous iterations.

In summary, the work group recommends that communities be viewed as the biological structural component of ecosystems. For an expanded suite of possible stresses, the structural endpoints (species number, abundance, shifting competitive state, etc.) remain constant in their importance across stresses and across ecosystems. The information available to describe the endpoint for a given stress-endpoint combination will vary, so the acquisition of new information and the incorporation of this knowledge into the ecological risk assessment process must be ongoing, and the ecological risk assessment process should remain fluid.

3.4. Ecosystem Work Group (David Weinstein, Chair)

3.4.1. Introduction

Ecosystem-level considerations often have been insufficiently treated in ecological assessments because of the complexity of interconnections within the ecosystem, the difficulty of identifying the circumstances under which indirect pathways might cause effects, and the failure to recognize the importance of these indirect pathways. However, since the ecosystem serves as a mediator of the interactions within and among populations, within and between trophic levels in communities, and between each population and its abiotic environment, the likelihood is high that ecosystem-level processes influence the stress-response relationship between a stress and ecological characteristics or endpoints of concern within the natural ecosystem. The consequences of such influences are high and potentially of great magnitude, since ecosystem processes, such as nutrient regeneration and organic matter transformation, are the means by which the suite of species within an ecosystem receive the resources necessary for their sustenance. Consequently, the work group viewed the method by which these ecosystem processes will be considered essential in risk assessment.

3.4.2. Criteria for Selecting Endpoints

A major phase in the ecological risk assessment process will be the identification of the critical endpoints of relevance to ecosystem-level considerations. This work group attempted to define the criteria that should be used to select these endpoints.

The first step is to recognize that the endpoints will have to be selected with reference to a specific ecosystem and specific stress in question. It is conceivable that each ecosystem will have a separate list for each stress. However, it is anticipated that once these lists are constructed, similarities across the lists for different stress-ecosystem combinations will permit aggregation, reducing the total number of cases for which unique lists will be required. Development of the ecological risk assessment guidelines should address this possibility.

3.4.3. Example Set of Criteria

There are two criteria that the work group initially determined to be important for selecting endpoints of concern once the specific ecosystem and stress have been identified:

1. The endpoints must characterize the ability of the ecosystem to sustain its structure (e.g., physical structure, diversity) and function (e.g., nutrient regeneration, carbon flows). In other words, a change in the endpoint would indicate a change in the ability of the ecosystem to sustain normal structure and normal function. A significant change in the endpoint, therefore, would be inevitably followed by a change in the capability of the ecosystem to continue to support its cast of species present at the time of the stress.

2. The endpoint must involve a characterization of the stocks and flows in the ecosystem. The work group recognized that the quantities in standing stocks of material and in the flows of energy, carbon material, and nutrients between these stocks are intimately related to the ability to sustain normal processes and therefore are themselves key to understanding the impacts of stresses.

a) Examples of structural stocks and flows

- diversity;
  - traditional diversity,
  - functional diversity, and
  - diversity of economically important species;
- physical habitat;
- spatial heterogeneity; and
- natural disturbance regime.

b) Examples of functional characteristics

- regeneration of nutrients;
- natural detoxification processes;
- potential for increasing toxicity; and
- major flows.

These criteria were constructed with specific aquatic ecosystems in mind, although they appear to be sufficiently general to be used for any ecosystem. Nevertheless, the list may need to be expanded as other ecosystems are given detailed consideration, a process that should be begun early in the process of developing ecological risk assessment guidelines.

3.4.4. Example List of Endpoints

Using the above criteria of characterizing sustainability and/or stocks and flows, a list of endpoints was created for the shallow-water marine ecosystem type, using an examination of the important characteristics likely to be affected by nutrient addition. This list was considered to be appropriate for freshwater lake and river ecosystems as well.

- Water turnover through the benthos. Under nutrient addition, maintenance of water quality and clarity is dependent upon the rate of filtration by the benthos. The benthos will remove particulates from water as it passes through the organisms, buffering the rest of the ecosystem from changes in light availability associated with algal blooms that otherwise would result from an influx of nutrients. Consequently, a measurement of the amount of water that can be processed per unit time by the benthos will reflect the relative degree to which an aquatic system can buffer nutrient addition.

- Change in composition within a trophic level. The ratios of key population guilds (or functionally similar units) within a trophic level will be critical for the maintenance of resource generation or regeneration rates upon which the rest of the ecosystem depends. For example, shifts from the relative abundances of blue-green and green taxa of algae will profoundly influence species dependent upon one or the other of these groups for fixation and generation of nutrients or carbon. Nutrient additions have been demonstrated to cause a shift in this ratio.

- Relative energy flow through the grazing food chain versus the detritus food chain. Energy fixed through photosynthesis or entering the ecosystem through material influx will be utilized by either grazing organisms or detritus decomposers. Depending on

which of these pathways predominantly uses the carbon in an ecosystem, the response to alteration in energy flow will be characteristically different. Since entire subsystems are developed to utilize the nutrients released by these processors, the response will quickly be felt throughout the ecosystem. Therefore, a shift in the relative flow through these two pathways will precede a significant change in the ecosystem.

- Anoxia, or low levels of dissolved oxygen. The level of dissolved oxygen has been well documented as a critical characteristic determining the ability of aquatic ecosystems to sustain their structures and functions. Low levels of dissolved oxygen often lead to noxious algae blooms.

- Productivity in different trophic levels. Major fish production is probably the most widely recognized marine ecosystem characteristic of concern. Because of the tight coupling between fish productivity and productivity of other trophic levels, each is a key endpoint and an endpoint demonstrated to be potentially affected by nutrient addition.

- Physical structure. Most species in most ecosystems are dependent upon a specific physical structuring of the system. They utilize this structure to acquire the quantities of resources needed, or survive by the growth restrictions the structure places upon their competitors. Consequently, changes in physical structure are likely to change the pattern of resource availability and therefore the ability of species to compete and survive.

- Ratio of recycled to new nutrient input. Organisms in ecosystems become adapted to a characteristic pattern of nutrient availability. That pattern is vastly different if the nutrient availability is recycled through biologically mediated (e.g., through decomposition) versus physically mediated (e.g., through rainfall input). Shifts in the ratio of recycled to new inputs will therefore result in shifts in the competitive ability of species and, subsequently, the compositional mix that depends upon those relative abilities.

- Change in the disturbance regime. The work group considered the lists of endpoints that would be generated for the shallow-water marine ecosystem type under different types of stresses, namely pesticide input, species introductions, and changes in hydrology. No new endpoints were identified, although after brief study several endpoints did not appear to be appropriate for one or more of these additional stresses. As the new stresses were considered, ways that each of the originally suggested endpoints could reflect the ability of the marine ecosystem to sustain itself under the stress were identified, leading to the suggestion that this list might be comprehensive across different types of stresses. Since, as previously mentioned, the endpoint list was also comprehensive for freshwater ecosystems, the work group suspected that the total number of lists needed might in practice not be large.

The next step in the process would be to consider a different ecosystem type, such as forests, and compile the list of characteristics reflecting the ability of those ecosystems to sustain themselves under different kinds of stresses. Following this task, it would be determined whether a change in the criteria is necessary to cover the endpoints that should be identified in each new type of ecosystem.

These steps are recommended to occur early in the process of developing ecological risk assessment guidelines.

3.4.5. Practical Considerations

In practice the work group found it easier to select a particular stress-ecosystem combination (such as pesticide addition to marine ecosystems), list the set of ecosystem characteristics of importance (hereafter referred to as endpoints), and identify the criteria that were used to select items for that list. This process was repeated for different stresses for a given ecosystem, with items added to the list as warranted by consideration of the different stresses, and modification of the selection criteria following if required. Presumably the same steps could be followed for each stress for a different ecosystem type, yielding a separate list of endpoints for each stress-ecosystem combination, but a single set of criteria applying to all endpoint lists.

3.4.6. Issues Requiring Further Consideration

- Should classification of ecosystems be based on functionality instead of the traditional classification based on the physiognomy of the dominant organisms?

  For the purposes of risk assessment, two ecosystems with similar rates of energy and/or nutrient processing and similar pathways of material and energy flow might have much more similar risks, and should therefore be treated as a single category, than might two ecosystems classified together because they are both dominated by large trees, for example.

- Should classification be further subdivided by natural disturbance frequency?

  Often the rate and frequency of natural disturbance have shaped the characteristic rates of material and energy processing in ecosystems. Therefore, the risks of damage by pollutants are likely to be more similar among ecosystems experiencing similar rates of disturbances than among all forests, or among all lakes, or among all streams, etc.

- Where do we put managed ecosystems, such as agricultural systems, in this classification?

- In determining endpoints:

  - Who determines what constitutes acceptable and unacceptable changes?
  - Do endpoints depend on spatial and temporal scale?
  - How do we deal with natural variability in determining a probabilistic dose response?

4. SCIENTIFIC FEASIBILITY ISSUES

4.1. Introduction

Having examined the state-of-the-science relative to the theories and principles available for assessing risks at the various levels of ecological organization, two work groups were charged with determining the feasibility of conducting ecological risk assessments in aquatic and terrestrial ecosystems. These work groups focused on determining which methods and models are currently available for assessing the risk from both chemical and nonchemical stresses and identifying additional research that will be needed over the next decade. This latter information is important to EPA for formulating a strategy for its ecological risk guidelines program.

4.2. Aquatic Ecosystems Work Group (Tom Duke, Chair)

4.2.1. Scientific Feasibility Issues

This work group addressed the feasibility of utilizing various ecological effects endpoints in an ecological risk assessment procedure. Three feasibility categories were discussed: those endpoints ready to be used immediately, those endpoints ready within 5 years, and those endpoints ready within 10 years. Research needed to develop new effects endpoints or improve present ones also was discussed.

The work group defined feasibility, identified four aquatic ecosystem types, selected endpoints for effects from lists provided by speakers earlier in the workshop, and identified biological responses. "Feasibility" was considered in terms of methods and interpretation, because many examples were presented where methods to measure a specific endpoint are presently available (or soon will be available), but the capacity to interpret the results of the measurement will require another 5 or more years of research. The group decided that a matrix approach is required to address the feasibility issue and would involve various aquatic habitats, effects endpoints, and levels of biological responses. A simple division of the aquatic environment into marine and freshwater ecosystems was considered to be inadequate. A more habitat-oriented approach was recommended and resulted in selection of four types of aquatic ecosystems: flowing water, shallow embayments, deep embayments, and wetlands. Based on presentations made earlier in the workshop, endpoints were selected under the general category of structure, function, and physical environment. Also, a biological response hierarchy of individuals, populations, communities, and ecosystems was selected on the basis of previous discussions at the plenary sessions.

The work group discussed a general approach to ecological risk assessment that would be from the top (of biological hierarchy) down and from the bottom up. That is, one would assess the particular ecosystem under question through literature, research, expert scientific judgment, etc., and locate specific ecosystem structural and functional attributes that could be impacted by the stress or stresses involved. Next, information would be developed at the individual organism level. This information would be processed through models and other means to the population and possibly community levels. The protocol at the population level would be:

a) scientific assessment of the stress;

b) an individual viewed as a dynamic organism; it is a function of the stress (e.g., lipophilic chemicals require quantitative knowledge of lipid dynamics in the individual);

c) exposure (this must be coupled with the individual--the receptor);

d) effector (e.g., the presence of the stress in the individual must be translated to individual effects [QSARs]); and

e) population effects determination (the sum of individual effects is translated to population-level endpoints).

The matrix for assessing the feasibility of using specific effects endpoints in ecosystem risk assessment is presented in table 1. Feasibility of the methodology (designated "M") and interpretation (designated "I") for each endpoint is rated numerically as follows:

- 0--indicates that the method is immediately available and utilized by EPA and other agencies or agreed upon by the scientific community, and that a sufficient body of knowledge and expertise exists presently to interpret the quantification of the endpoint;
- 5--indicates that the method or interpretative capacity is 5 years in the future; and
- 10--indicates 10 years or more of work is required.

It was the opinion of the work group that the numerical designations should be viewed in a relative, not absolute sense. The list of endpoints is obviously incomplete and should be viewed as an example of how endpoints can be evaluated. A detailed listing of endpoints should be an early component of the ecological risk assessment guidelines process.

The three categories of endpoints examined were based on measures of biological structure, function, and physical environment (table 1). The extent and level of complexity to which these structural and functional endpoints interact and could be measured and analyzed are nearly limitless. The work group attempted to make the following rather simple "first-cut." Aquatic communities, for example, can be classified as planktonic or benthic and within each of these categories can function autotrophically or heterotrophically. Such an approach would be especially helpful in focusing food-web measurements.

The physical environment endpoint was included to account for changes in abiotic components of the ecosystem associated with impacts of a stress. Changes in the physical environment of an ecological system could of course bring about changes in the biological structure (indirect effects).

Table 1. Feasibility Matrix

Ecosystem-Level Endpoints	Habitat							
	Flowing Water		Shallow Embayment		Deep Embayment		Wetlands	
	M[a]	I[a]	M	I	M	I	M	I
A. Biological Structure								
Biomass Partitioning - Quantify relative stocks by meaningful groups (e.g., plankton, benthos, autotrophs, heterotrophs; diatoms, flagellates, blue-green algae)	0	0-5	0	0-5	0	0-5	0	0-10
Species Enumeration - including diversity	0	0-5	0	0-5	0	0-5	0	0-5
Food Webs	0-10	0-10	0-10	0-10	0-10	0-10	0-5	10
B. Biological Funcation								
Total System Metabolism - Integrated holistic measurement of entire system metabolism (e.g., upstream-downstream, and diel freshwater oxygen concentrations)	0	0-5	0-5	0-10	0-5	0-10	5	10
Component Community Metabolism - (e.g., light/dark bottles, benthic chambers)	0	0-5	0	0-10	0	0-10	5	10
Carbon and Nitrogen Flow - (e.g., internal dynamics and external sources and sinks)	5	5-10	0	0-5	0	0-5	5	5-10
C. Physical Environment (i.e., substrate characterization, flow regime, depth, temperature, light, turbidity)	0	0	0	0-5	0	0	0	0-5

Table 1 (cont.)

Population-Level Endpoints[b]	Biological Systems							
	Fish		Inverte-brates		Plankton		Other Vertebrates	
	M	I	M	I	M	I	M	I
Growth	0	0-5	0-5	5-10	0-5	0-5	0-5	0-5
Survival	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10
Reproduction	0-5-10	0-5-10	0-5		0	0-5	0-5	0-5
Structure								
· *age*	0	0-5		5-10	0-5		5-10	
· *size*	0	0-5	0-5	5-10	0-5		5-10	
· *physical variables*	0-5	5-10		5-10	0-5		5-10	

[a] M - Feasibility of methodology
I - Feasibility of interpretation
Numbers in the table reflect the estimated number of years until methodology is available or knowledge is sufficient to interpret endpoint data. See text for additional explanation.

[b] Categories for the population matrix differ from the ecosystem matrix because the population-level endpoints are more closely related to biological systems than to habitat.

4.2.2. Research Needs

The work group identified the following general research needs:

- Develop information on the frequency and magnitude of natural disturbances. Effects linked to anthropogenic stresses must be compared to underlying variability linked to natural variation. A critical need exists to characterize natural variation and to address signal-to-noise issues at the ecosystem level.

- Develop a strong ecological theory concerning impact of stresses on structure and function of ecosystems. In general, there is only a vague understanding of the linkage between stresses and changes at the ecosystem level. There are notable exceptions; for example, there is much evidence that may be used to predict ecosystem responses to nutrient additions and organic additions. An understanding of the way these ecosystem-level characteristics respond to stress and disturbance is needed. Except for ecosystem-level (mesocosm) experiments, experimental approaches are not available. Interpretation at the ecosystem level may not be generalizable for many stresses. There is a need to develop protocols so as to avoid studying each stress. These protocols may be similar to application of quantitative structure-activity relationships (QSARs) to population-level studies.

- Identify general exposure/effect responses for ecosystem endpoints from all available sources (meta analysis).

- Determine the interrelationships among local ecosystems that propagate effects to larger (landscape or global) scales.

- Improve the capacity of models to extrapolate from laboratory to field and from individuals to populations and communities.

The following comments and research needs are related to the endpoints used in the feasibility matrix at the population level of organization:

- Abundance--Measurements of abundance are feasible and routinely done. For fish, relative abundance is usually easier to measure than absolute abundance. Populations distributed over large areas can be difficult to estimate. Foreseeable research is unlikely to lead to significant improvements.

- Age/Size Distribution--Measurements of age/size distribution for fish are feasible and routinely done. Precision is higher than for abundance estimates. This measurement is sensitive to stress--it is often used to assess status of exploited populations. Some improvements in aging techniques are possible from research on scale and otolith analysis. Size/distribution is straightforward for invertebrates. For some mollusca, age is estimated using techniques similar to those used for fish. For larger invertebrates, age/size can be an indicator of stress. For smaller invertebrates, it is more an indicator of predation intensity. Research is unlikely to lead to improvements.

- Reproduction--Measurement of reproduction for fish is feasible and routinely done. Reproductive status (mature or immature) is easy to determine. Fecundity is feasible, but can be difficult to estimate in some species. Size-at-maturity is a commonly viewed indicator of over-exploitation. For invertebrates, feasibility varies with taxon. Utility as an indicator of stress is unclear.

- Survival--Measurement of survival for fish is usually estimated indirectly from abundance and age-distribution time series. Standard methods are available; improvements are unlikely. For mammals, survival rates can be obtained directly from radio-collared animals. Improvements in technology (e.g., size, cost of transmitters) are likely in the near-term. Survival is an indicator of total stress level, but without further information it does not reveal source of stress. For invertebrates, survival usually is estimated indirectly from abundance and reproduction.

- Growth--For fish, past growth histories often can be estimated from scales or otoliths. Growth can be used as an indicator of stress. Improvements are possible with further research on otolith analysis.

- Physiological Status--For fish, simple condition indices are widely used now. Some physiological, histopathological, and biochemical measures are now being used, principally in research, as indicators of exposure and/or response to contaminant. In general, most of these have proved difficult to interpret as indicators of effects. Some indicators have been shown to be selective indicators of exposure to specific classes of chemical stresses. This is an extremely important research area in which much progress is possible. It provides a means of separating the effects of chemical stresses from the effects of other natural and anthropogenic stresses.

4.3. Terrestrial Ecosystems Work Group (William Smith, Chair)

4.3.1. Introduction

In an effort to identify research required to improve ecological risk assessment methodology, the Terrestrial Ecosystems work group identified "generic" strategies for risk assessments at the population and ecosystem levels (figures 2 and 3). These figures suggest current state-of-the-science capability and imply that additional data are required for more effective ecological risk assessments. From this exercise, the work group developed specific suggestions for research needs that would strengthen ecological risk assessment capabilities. These needs are presented under stress characterization and ecological effects characterization categories.

Figure 2. Current Strategy for Ecological Risk Assessment: Population Scale

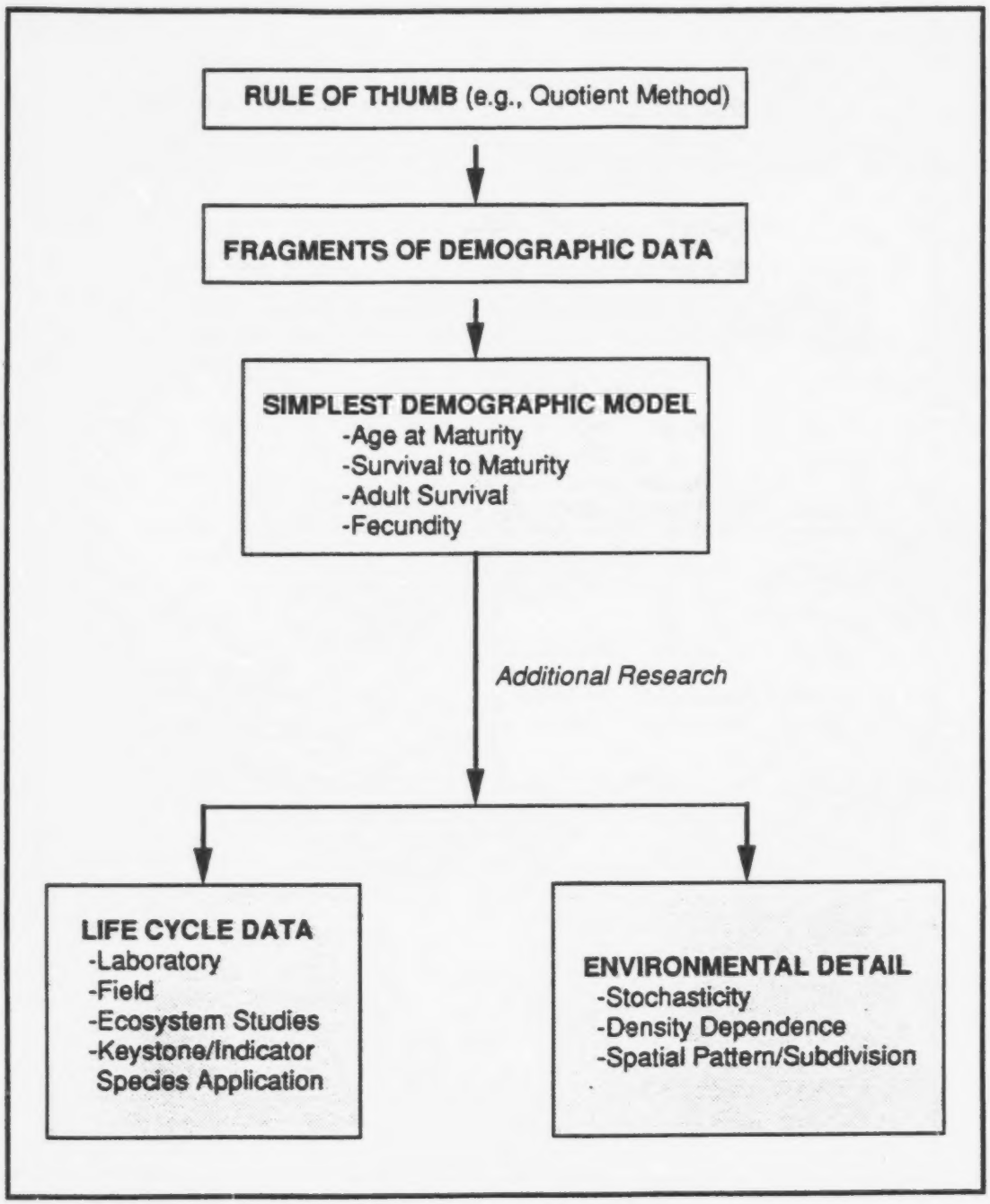
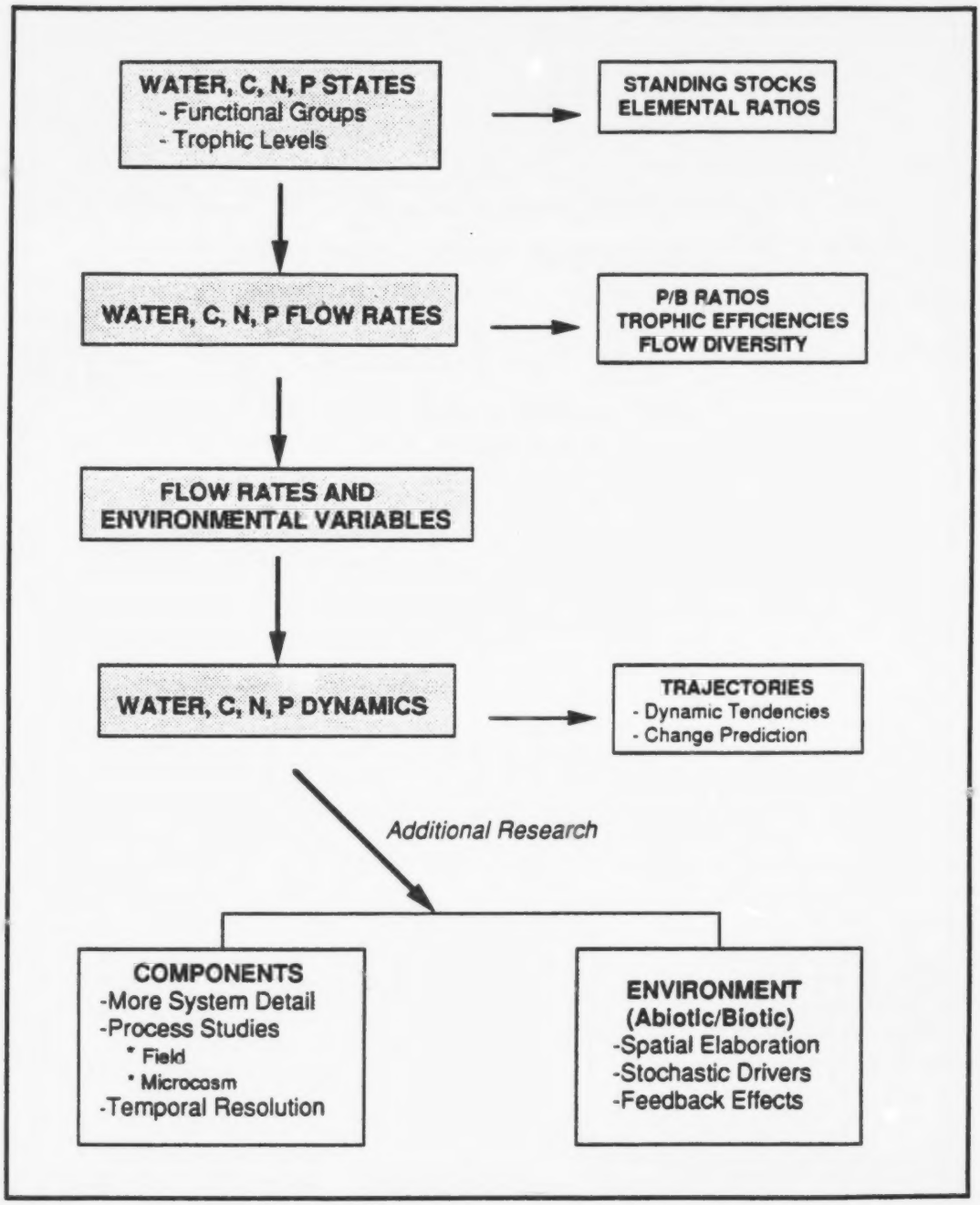


Figure 3. Current Strategy for Ecological Risk Assessment: Ecosystem Scale



4.3.2. Stress Characterization Research Needs

A primary research challenge in this area is the linkage between stress monitoring (exposure) and dose (e.g., amount/duration of a chemical at a biological receptor site of action). For ecological risk assessment, the need is especially great for improved understanding of dose at different ecological hierarchies (i.e., individual, population, community, ecosystem, landscape); time scales; and spatial scales. Additional research on dose kinetics also is required. Improved understanding of episodic (peak) exposures versus chronic, longer term exposures is essential. Linkage of exposure data to indirect as well as direct ecological effects also is needed.

4.3.3. Ecological Characterization Research Needs

Ecological understanding is improved by increased fundamental understanding of how ecological systems are structured and how they function. As a result, continued advancement of basic ecological understanding is essential for improving ecological risk assessment strategies. A major challenge is to partition anthropogenic stress effects from natural stress effects. Natural stresses are varied, often recurrent, and have large associated variances. Research is needed on strategies to partition subtle stress from dynamic system function. Understanding natural disturbance and ecological responses (e.g., importance of functional redundancy, estimation of resilience and recovery times) represents an opportunity to advance our ability to assess anthropogenic disturbances. Once a site-specific problem has been selected for assessment, improved methodologies are needed to integrate relevant existing information and data sets. Continued efforts to improve extrapolation of information from laboratory to field, from species to species, and from one ecological scale to another are needed. Multiple-stress interactions must be more adequately documented.

Factorial experiments and models provide experimental opportunities. Models developed or applied in ecological risk assessments need to be standardized. For example, consensus must be reached on the most important model parameters. How do stresses affect these parameters? Sensitivity and formal uncertainty analyses must be performed. Further understanding of ecosystem linkages is needed; the ability of a stressed forest to influence an associated stream or lake ecosystem is one example. The significance of pattern for regional ecosystem and landscape scales must be understood. We must account for the spatial heterogeneity of landscapes. Similarly, an understanding of the significance of landscape pattern for habitats and species "source and sink" areas within landscapes is needed. More effective tools must be developed to integrate geographic information systems and remote sensing data.

5. SPECIAL TOPICS

5.1. Introduction

During the first plenary session of the Miami workshop, stress characterization and ecosystem classification were identified by the workshop participants as issues that warranted additional attention in the workshop. Knowledge of the properties, distribution, behavior, and exposure patterns of stresses was deemed to be as important as understanding ecological effects, both being inextricably interwoven throughout the risk assessment process. Historically, ecological risks have focused on chemical stresses. Recent reviews of current and future environmental problems, however, have emphasized the increasing importance of nonchemical stresses (U.S. EPA, 1990), the interaction of multiple stresses, and the abiotic modulation of stresses (U.S. EPA, 1991). Workshop participants considered complementing the traditional structural classification of ecosystems with a classification system based upon the functional characteristics of ecosystems. This type of classification would be process based, have the advantage of not being linked to and limited by classic taxonomic classification, have diagnostic value, and have a high degree of predictive value independent of ecosystem type. The following section reports on the conclusions of the Stress Characterization and Ecosystem Classification work groups.

5.2. Stress Characterization Work Group (Robert Huggett, Chair)

5.2.1. Introduction

The most widely used model for risk assessments was developed for human exposure to hazardous chemicals (NRC, 1983). This report stated that risk characterization is a function of both hazard and exposure. In this case, it is useful to define "hazard" as the inherent ability of some stress to cause harm and "exposure" as the magnitude of stress on the system. In the case of a single chemical and a single species, a dose-response relationship would relate the exposure to the hazard to yield the risk estimate.

At the single-species/single-chemical level, this model is straightforward and useable for ecological risk assessments in either terrestrial or aquatic environments. It is at higher levels of biological organization or when the exposure is to nonchemical and or multiple stresses that our basic understanding of biochemistry, physiology, and ecological interactions, and our ignorance of the fate-and-transport of chemicals, distribution of nonchemical stresses, etc., limit the accuracy of the risk characterization. This section attempts to expand on some of the characteristics that link chemical, physical, or biological stresses and exposure.

5.2.2. Stress Characterization

Consideration of exposure comes into play in at least two ways when performing an ecological risk assessment. Exposure considerations are involved in the initial steps of the risk assessment process, namely, in the conceptual problem definition phase, where exposure is utilized to help define the scope of the problem. By considering the temporal scale of the exposure (i.e., acute, episodic, or continuous) and the spatial scale over which exposure occurs (i.e., local, regional, or global), this information can be used to identify populations, communities, and ecosystems potentially at risk and, thereby, help define the scope and nature of the ecological risk assessment. After this

initial scoping phase, stress characterization (exposure assessment) seeks to quantify the magnitude, frequency, and duration of contact of the stress with the receptor.

The metric produced through the stress characterization assessment must be keyed to the requirements of the stress-response assessment. For example, an exposure metric geared to individuals in the population (e.g., $mg \cdot kg^{-1} \cdot day^{-1}$) would be appropriate for population risk assessment. On the other hand, when higher level (e.g., community and ecosystem) effects are the focus, the appropriate stress or exposure metric should be keyed to the stress-response relationship available at these levels. This stress/exposure metric may be expressed in units of flux (e.g., amount of stress per unit area per unit time). Otherwise, the stress/exposure metric should be keyed to a lower level of biological organization and the effects extrapolated through modeling to the higher levels.

Characterization of populations, communities, and ecosystems is an important and often problematic aspect of ecological exposure assessment. Unlike the populations that are the focus of human health risk assessments, generally there is much less information available about activity patterns, abundance, demographics, and life histories of nonhuman populations. This information is essential for constructing necessary scenarios of how populations come into contact with the stress. Although this type of information may be available for populations of commercial interest, generally it is not available or has not been combined into a useful form for ecological risk assessment purposes.

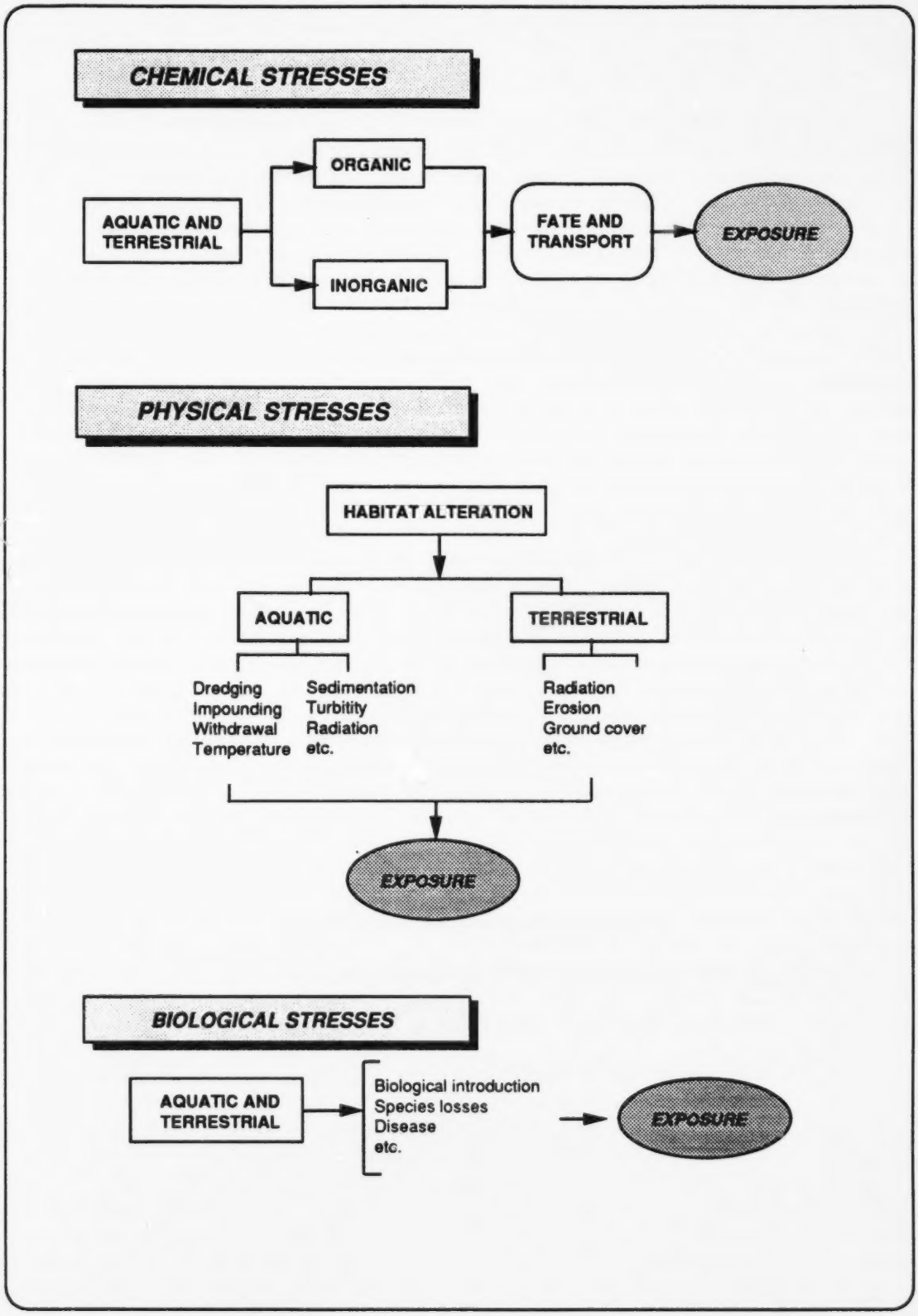
Another important consideration in ecological exposure assessment is how exposure to a stress may alter natural behavior patterns, thereby affecting further exposure. In some cases, this may lead to enhanced exposure (e.g., increased preening by birds after aerial spraying), while in other situations initial exposure may lead to avoidance of contaminated locations or food sources. Little is currently known about such behavioral modifications and how they may affect exposure by either enhancing or mitigating it.

It is important to elaborate on the properties of stress relevant to ecological risk management. The term "stress" has connotations that may be misleading under certain circumstances. The following is an attempt to focus a future definition of stress on the factors that must be considered in ecological risk assessment. First, a stress is characterized by its:

- quality: chemical, physical, or biological;
- intensity: concentration, magnitude, abundance/density;
- duration: acute (short-term) versus chronic (long-term);
- frequency: single event versus recurring or multiple exposures;
- timing: time of occurrence relative to biological parameters such as spawning cycle; and
- scale: spatial extent and heterogeneity in intensity.

One approach for categorizing the quality of stress is illustrated in figure 4. In this figure, the fate, transport, and exposure of organic versus inorganic chemicals are distinguished. This portion of the scheme applies most directly to the introduction of chemicals to an ecosystem from an outside

Figure 4. Example Categories of Stressors



source. Other stresses that affect habitat quality may be classed as physical. The examples listed in figure 4 each influence some physical property of an organism's habitat (e.g., temperature, light penetration), or they may influence chemical properties of that habitat. For example, removal of riparian vegetation in high-order streams may influence water temperature by increasing exposure to sunlight. Discussion of biological stresses will follow.

The intensity of a stress is a measure of concentration (chemical), magnitude (physical), or abundance/density (biological). The implication is that the intensity of a stress is related in some way to its potential impacts. An example is a dose-response curve for some chemical additives. This curve may be linear or curvilinear and may reflect certain threshold effects. Note also that the shape of an "intensity-effect" curve may vary as a function of other stresses incurred by the system (i.e., multiple stresses) or by the duration, frequency, and timing of the stress.

The duration of a stress may be measured directly by change in its intensity through time. An acute stress may be detected at some intensity for only a short period of time (e.g., a burst of ionizing radiation) or may persist over longer periods because of fate-and-transport properties (e.g., solubility) or source (e.g., constant supply, acid mine drainage). The frequency of occurrence of a stress is particularly important if its effects are extreme or if its effects are cumulative. For example, release of some chemical stresses may occur from some impoundments/lagoons whenever an extreme storm event occurs that overflows the impoundment. The substance may cause acute effects or be accumulated in tissues. Reoccurring exposure to ionizing radiation may cause harmful cumulative effects. On the other hand, recurring exposure to some stresses below certain thresholds of impact may allow a system to adapt to that agent.

The seasonality of a stress becomes important if it is a single-event or low-frequency stress. For example, a single event/release/exposure for even an extreme stress may have minimal effects if it occurs when the biota are dormant. The spatial scale and heterogeneity in the intensity of a stress also must be considered in an ecological risk assessment. Airborne chemical stresses, for example, may be chronic in nature, but their intensity may vary widely through space (and time) as a function of air-mass dynamics and other conditions affecting deposition and exposure.

Biological stresses fall into a separate category, exemplified by species introductions, species extinctions, or species extirpations (i.e., local extinctions). Species introductions may be deliberate, as seen in biological control efforts using pest parasites or pathogens or in species reestablishment efforts, but we are most familiar with species introductions that may be accidental (e.g., gypsy moth) or simply unanticipated (e.g., successful establishment of ornamental species). Because of the nature of biological stresses, these warrant special attention. For example, at the local scale (i.e., dealing with stresses from a point source), point-source populations are directly involved, and it may not be useful to quantify directly the effect of a stress. That is, for many of the stresses discussed thus far, impacts may be extrapolated from dose-response information to population-level effects. In the case of biological introductions, the mechanism of action is at the community level through disruption of inter-specific interactions. Therefore, quantifying this kind of effect would best be done at the level of the guild or functional group, where changes in competitive relationships would first be observable. In the case of parasite or pathogen introductions, measurement of community-level phenomena is not appropriate, since the level of action is at the individual level (i.e., the host organisms) and would have patterns of effects similar to those deriving from toxicants and similar stresses acting on individuals.

5.2.3. Characteristics of Exposure Assessment

Exposure to stresses generally occurs at the individual level; however, expression of that exposure can be measured at the population or higher levels of organization. This characteristic principle of exposure may hold true for direct effects only. The sensitivity to a stress may vary among individuals of a population and among populations of a community. After direct effects occur, remaining populations may not have the same genetic pool as before exposure. The population(s) may then be more or less able to interact (e.g., competition, predation) in a community, thereby further altering the potential for exposure at the community level.

For chemical stresses, the exposure of a population or community often is simplified by assuming that all individuals in a population or community are exposed to the same concentration. When the concentration varies spatially, another set of assumptions could be used to conduct the exposure assessment more accurately. For example, for mobile organisms, the spatial arithmetic average could be used to assess exposure of the population by assuming that each member of the population is randomly moving in the averaged area. The spatial arithmetic average again could be used to estimate risk to the population of sessile organisms by assuming that the organisms are distributed randomly in the area. For a community of organisms, the spatial average could be used to assess exposure by assuming that all individuals in the community are either moving randomly in the area or are distributed randomly over the area.

Many of the same assumptions can be used when assessing physical alterations. For example, exposure to stresses such as hydrologic changes, sedimentation, or dredging can be assessed by assuming that all individuals in a population or community are exposed to the same amount of the stress. When assessing physical alteration of habitat (e.g., decreased number of nesting or spawning sites), exposure estimates can be simplified by assuming that all the individuals in a population will randomly contact the altered habitat, or that the altered habitat is randomly distributed within the spatial boundaries of the population. In both of these cases, the magnitude of altered habitat in the population's range can be used to estimate the population's exposure.

5.2.4. Measurement

Exposure to hazardous chemicals and other stresses can be approximated in one of two ways. First it can be estimated by model predictions. The physical and chemical properties of the stress can be combined with the biochemical and physiological properties of the organisms in question in such a way as to yield predictions of the magnitude and duration of the stress. The other way to estimate exposure is to measure it either directly or indirectly. Determination of tissue residue levels and measuring body burdens of chemicals are examples of direct measurements. A major drawback to tissue residue methods of estimating exposure to chemicals is that often the chemical is rapidly metabolized and excreted. Therefore, only acute and/or perhaps high-magnitude exposures may be noted.

Biomarkers often are used as indirect measurements of stress. In this context, biomarkers are defined as biochemical, physiological, or histopathological manifestations of anthropogenic stress. Among the assays that utilize biomarkers to measure exposure indirectly are:

- protein induction, such as cytochrome P450-induction to indicate exposure to petroleum hydrocarbons or to some chlorinated organic compounds;

- immune system dysfunction resulting from exposure to polynuclear aromatic hydrocarbons as well as some other chemical and physical stresses;

- DNA alterations, such as covalent bonding of exogenous chemicals or strand breaks indicating exposure to hazardous chemicals; and

- bile metabolites, which measure the response of enzymatic activities on foreign chemicals.

There are numerous other assays that offer the potential to indicate that the organism has been exposed. A major drawback with biomarkers, however, is that our present understanding of the linkages between biomarker response and effects is very rudimentary. It should not be assumed that a biomarker response necessarily translates to an adverse effect. The recent research emphasis in this field may rectify this situation.

5.2.5. Sources

Source identification and estimations of relative contributions by various sources becomes critical when determining stress and exposure in the ecological risk assessment process. A significant component of this is development of some understanding of the uncertainty surrounding source identification.

Historical activity in this field has dealt primarily with the introduction of chemicals into aquatic environments via point sources. Conventional wisdom in this area would probably suggest that the uncertainty about source estimation is lower for aquatic ecosystems than terrestrial ecosystems. However, as we begin to consider a broader range of chemical introductions as well as nonchemical stresses affecting both aquatic and terrestrial ecosystems via point and nonpoint sources, it may be that this conventional wisdom breaks down. Atmospheric deposition of inorganic and organic compounds onto both aquatic and terrestrial ecosystems is poorly understood or estimated at this point. Opinion varies over our ability to measure or estimate both wet- and dry-deposition and resultant contributions to aquatic and terrestrial ecosystems. For example, concern over deposition as an important source of nitrogen to watersheds and associated aquatic resources such as the Chesapeake Bay has increased, but is still poorly understood. Similarly, atmospheric deposition of toxic organic compounds to terrestrial and aquatic ecosystems in the Arctic and upper Midwest is of apparent concern, but the uncertainty associated with source estimations is quite large.

Physical habitat alteration and biological stresses are relatively new areas to be considered in the ecological risk assessment process. Estimation of the sources for these stresses may require a somewhat different perspective than traditionally taken in source estimation in the chemical stress field; in some instances, the concept of "source" may not even be particularly useful for these classes of stresses.

The uncertainty of source identification and estimation may be greater in aquatic ecosystems than terrestrial. This might be especially true for physical habitat alterations such as sedimentation, water withdrawal, or thermal alterations in aquatic ecosystems. Classification of physical stresses along the lines of point and nonpoint sources may lead to a useful analogy for considering the source component. Dredging and impoundment as physical habitat stresses might be considered point sources, while sedimentation may be more appropriately considered nonpoint.

Biological stresses, such as species introductions, disease introduction, species removal, harvesting, or stocking practices (e.g., clear-cutting, overstocking of fish in lakes), are increasingly important stresses in ecological risk assessment. This class of stresses will often be assessed by their impact on biological interactions at the community level or perhaps changes in process rates at the ecosystem level. Ability to identify the source of these stresses will vary substantially with individual cases. In the case of management practices for biological components (e.g., overstocking), the source is quite apparent. The introduction of biological stresses in the form of disease causing organisms or exotic species often will be more difficult to trace as a source term and to develop any estimate of the uncertainty associated with this. In these instances, uncertainty about source identification and source contribution may be quite high.

The guidelines for ecological risk assessment should include specific recommendations for addressing the uncertainty of source identification and partitioning of various sources to final exposure. This uncertainty may well vary by stress class as well as ecosystem type. An integral component of developing this uncertainty also will be the evaluation of partitioning of fate-and-transport as it varies with source and system type (e.g., partitioning of organics in the sediment and water column).

5.2.6. Bioavailability

Given a specific source of known magnitude, intensity, and duration, fate-and-transport models can predict the distribution and persistence of chemical stresses in the environment. However, just because a stress is present in the environment at high concentrations does not necessarily mean that it is going to affect individuals in a dose-dependent manner. The actual bioavailability of the compound will depend on chemical properties of the compound, physical and chemical properties of the matrix it is in, and the distribution and life-history traits of the organism.

For example, in the case of hydrophobic organic contaminants in aquatic ecosystems, bioavailability will be determined largely by the lipid partitioning behavior of the compound (as indicated by its octanol/water partition coefficient, or K_{ow}). If it is in a sediment reservoir, the type of the particles and organic carbon content also will figure prominently in the determination of the bioavailability of the compound. If sufficient quantities of the compound are present in the water column, the dissolved organic matter present will affect the bioavailable fractions.

For inorganic stresses such as metals, different factors influence bioavailability. Whether or not the metal is free or in an organic form (e.g., mercury, selenium) will dramatically alter its bioavailability. Of free metals, it is generally thought that the free ion is more bioavailable. Determination of the free-ion activity requires detailed knowledge of all complexing agents present or use of ion-specific electrodes. For metals in sediments, it has been proposed that the concentration of acid-volatile sulfides controls the bioavailability of metals.

Once the bioavailable fraction of the stress in different components of the ecosystem is determined, it is necessary to consider properties of the organism. Will it encounter the stress in its diet, through diurnal exposure, and/or through respiratory surfaces? Does the organism possess behavioral, structural, or biochemical defenses to avoid bioaccumulation of the compound at the site of toxic action? How rapidly can the organism rid itself of the compound? All these parameters should be considered when addressing the bioavailability of chemical stresses in the environment.

5.2.7. Models

Mathematical models are increasingly being used to estimate fate, transport, and exposure. Yet many of the models have not been adequately field-tested or validated or are not easy to use. The input data are often very limited or of unknown quality. Available fate models typically look at only single source, medium, stress, and exposure pathways, and, therefore, often look at only part of the stress/exposure characterization spectrum.

At the present state-of-the-science, there are large uncertainties associated with model predictions of certain components associated with exposure. Among these are:

- sediment-water exchanges;
- other intermedia exchanges/transfers;
- bioavailability and biouptake;
- metabolism;
- extrapolations from lab to field;
- multiple routes of exposure;
- receptor behavior adjustment mechanisms; and
- characterizing receptors at risk.

5.2.8. Stress Research and Development Needs

The Stress Characterization work group identified a number of specific recommendations and needs for research (not necessarily listed in priority):

- transfer efficiencies and rates from abiotic to biotic components (e.g., dermal exposure from sediment, inhalation rates);
- testing and validation of biomarkers of exposure;
- better pharmacokinetic models to enable better interpretation of tissue residue data;
- better understanding of life history of organisms of interest;
- GIS or similar information system to overlay spatial and temporal scaling of stresses with spatial and temporal aspects of species and life stages at risk;
- factors affecting toxicity (e.g., pH, salinity, hardness) which are, for the most part, factors affecting exposure (research is needed to address this major area of uncertainty in exposure estimates);

- how to extrapolate across the levels of biological organization relative to type of stress, source of stress, magnitude of stress, etc. (e.g., given an exposure to a population, how are other parts of a community exposed through predation?);
- better methods to measure dry deposition;
- better and more validation of mathematical models (e.g., spray drift, equilibrium partitioning, bioaccumulation);
- better methods for predicting/estimating/characterizing stresses other than chemicals;
- more user-friendly analytical methods;
- quality-assured data bases for model inputs;
- methods to determine concentrations of polar organic contaminants in water, sediment, soils, and tissues;
- better understanding of feeding processes that affect bioavailability;
- a better understanding of biotic and abiotic features that control remobilization and release of contaminants in soils and sediments;
- the ability to model bed failure of cohesive sediments; and
- determination of the kinetics of sorption/desorption of hydrophobic chemicals.

5.2.9. Summary

Considerable progress has been made over the past decade in developing methodologies to determine or approximate exposure. Mathematical models that combine and relate various biotic and abiotic factors to yield estimates of exposure have or are being developed. The accuracy of exposure predictions appears to be increasing; however, several factors, if better understood, could greatly decrease the associated uncertainties. Among these is our present inability to model bed failure of cohesive sediments. Since a substantial fraction of the hydrophobic chemicals in an aquatic ecosystem are generally sorbed to fine-grained sediments, the deposition, resuspension, and transport of sediments are major factors controlling the exposure of aquatic organisms to chemical stresses. Of a similar nature is our ignorance of the variables controlling bioturbation and the resulting effects on the physical distribution and biological availability of sediment-associated chemicals. These are just two areas where research could provide answers that would benefit exposure predictions. Others include the relative uptake of material from food versus solution via the gills, and the kinetics and magnitude of uptake, storage, and depuration of hazardous chemicals in most of the noncommercially or recreationally important species that inhabit aqueous ecosystems. For physical and biological stresses, a better understanding of the interactions among biotic and abiotic components and biotic relationships is needed.

Even with these and other limitations, estimates of exposure can be made. The estimates will have an associated uncertainty that will be difficult to assess without large-scale field validation studies. However, more or less uncertainty may be acceptable depending on (1) the magnitude of the hazard, (2) the dose/response relationship, (3) the resource at risk, (4) the recovery time, and (5) the availability of alternatives.

5.3. Ecosystems Classification Work Group (Richard Wiegert, Chair)

5.3.1. Scale-Independent/Qualitative Ecosystem Classification

The traditional classification of ecosystems as lake, stream, forest, and grassland or freshwater, marine, terrestrial, etc., offers little to the person concerned with evaluating the impact of a potential stress. Here we propose a simple key that permits casting any ecological system into one of 64 distinct cells. Our criteria may be evaluated by a simple, subjective, ordinal system of measurement (qualitative) or by somewhat more detailed ratio measures (quantitative). In each scheme, the measures are dimensionless, conferring the benefit of scale independence.

We begin our classification with the observation that any ecosystem must be impacted by stresses delivered either through a gaseous (dry, terrestrial) phase or through an aqueous (wet, aquatic) phase.[1] Thus our first decision divides ecosystems along a continuum from a totally aquatic (pelagic) ecosystem to a totally terrestrial (upland) ecosystem.

As a second dichotomy, we have chosen to separate ecosystems according to the importance of the source of energy, whether totally autochthonous (e.g., pelagic, open ocean) or totally allochthonous (rare, such as the tops of high mountains). The rationale for this choice is the degree to which an ecosystem will be sensitive to stresses affecting primary producers.

Third, we choose to divide ecosystems according to the degree to which the initially fixed energy is degraded to heat through a series of biophagous (consumers of living resources) versus saprophagous (consumers of nonliving resources) pathways. This criterion separates ecosystems into those in which consumption is important in determining productivity in the previous trophic level (biophages) from those in which consumers only indirectly affect the production of their resources (saprophages). Those stresses affecting consumers in the first category can show "upstream" effects, whereas stresses affecting saprophages will not show such effects.

Our fourth criterion for ecosystem classification evaluates the importance of the ecosystem as an exporter of potential energy (i.e., is it a source or sink, degrading or storing more energy than it receives?). Knowledge of this characteristic is relevant to decisions about what impacts the delivery of a stress material to the system under consideration might have on coupled ecosystems. Storage of a material could have very different consequences than passage of the material to an adjacent ecosystem.

---

[1]In the case of stresses such as UV-B radiation, the filter is either gaseous or aqueous. Stresses delivered in precipitation are characterized by the medium into which the rain falls. Other exceptions are physical manipulations such as dredging and clear-cutting.

Our fifth criterion is the relative degree of nutrient recycling versus nutrient flux (recycling plus export). Qualitatively, we express this as the importance of nutrient recycling; as a ratio, we compute the rate of nutrient recycling versus the sum of recycling plus replacement. Stresses that affect the organisms responsible for any aspect of recycling (including inputs such as N-fixation) will obviously have different effects on ecosystems widely separated on this axis.

Lastly, we separate ecosystems on the basis of the frequency and duration/intensity of disturbance. Ecosystems subjected to frequent and prolonged or intense physical (catastrophic) disturbances are populated with organisms that have an evolutionary history significantly different than those that have evolved in a background of more moderate physical environmental variation. Clearly the former ecosystems, because they are persistent, have the capacity of more rapid recolonization and growth. We might expect that such ecosystems, everything else being equal, would recover more rapidly from the impact of a given stress.

This classification is clearly a very preliminary effort at devising a functional classification scheme for ecosystems. This scheme will aid the effort to predict the effects of stresses by providing a basis for identifying systems that may respond similarly to a given stress. We feel that it has the virtues of ease of application and freedom from scale effects. In its simplest qualitative form, the classification requires no more than a general, cursory knowledge of the ecosystem for implementation. To achieve the ratio level of measurement requires only the simplest of ecosystem measurements. The benefits to the environmental manager are that many redundant measurements can be avoided and the necessary measurements more clearly delineated.

The proposed classification may be used without further analysis simply by comparing each of the six criteria with the possible effect of the stress on that criterion. For example, a stress delivered in water can be eliminated from consideration on the basis of criterion number 1 if the ecosystem is entirely terrestrial.

A method (or methods) of representing the values statistically to obtain some weighted assessment of sensitivity as a whole will be more generally useful. This approach calls for much additional consideration about the ways in which the criterion values can be graphically or statistically displayed. This in turn requires some evaluation of how interdependent the criterion are, whether to weigh them, and whether they should be nonlinear. We feel that this is a classification approach of considerable potential value, but one that will require much more work. The work group recommends that such activity be an early focus of the ecological risk assessment guidelines development process.

6. ISSUES IN ECOLOGICAL RISK ASSESSMENT

6.1. Background

Recently, there has been considerable interest in ecological risk assessment within and outside EPA. The National Academy of Sciences Committee on Risk Assessment Methodologies (CRAM) conducted a workshop to examine the feasibility of using the human health paradigm for ecological risk assessments. EPA's Risk Assessment Forum recently conducted a series of colloquia directed at addressing issues in ecological risk assessment (U.S. EPA, 1991), one of which was devoted to the question of an ecological risk paradigm. A Risk Assessment Forum work group is developing a framework for ecological risk assessment. Several participants at the Miami workshop have been participants and reviewers in both these activities and are aware of the philosophy, approaches, and limitations of these activities. Because all these activities were occurring essentially concurrently, a consensus statement of the ecological risk paradigm or even a detailed description of the risk assessment process was not available at the time of the Miami workshop. The lack of a clearly defined ecological risk paradigm was a limitation since one of the workshop goals was to recommend possible titles, subject matter, and contents for future ecological risk assessment guidelines.

Recognizing this, workshop organizers convened a third special work group (the Road Map work group) to examine and describe the risk assessment process at a level of detail necessary to:

- understand how the three-dimensional matrix of stress, ecosystem type, and ecological hierarchy could be aggregated to determine the ecosystem(s) at risk;
- illustrate the importance of defining the endpoints in the ecological risk assessment process;
- illustrate the interrelationships between stress and ecology;
- identify the important scientific issues that would require in-depth technical support in future guidelines; and
- use the process and issues to recommend the subject matter and contents of future ecological risk assessment guidelines.

6.2. Characteristics of Ecological Risk Assessments

Ecological risk assessment is the process of qualitatively or quantitatively estimating the magnitude and probability (when feasible) of biological effects from exposure to individual or multiple stresses. The process basically evaluates two fundamental types of scientific information: the ecological effects resulting from co-occurrence with a stress, and the spatial and temporal intensity and duration of the stress. To assess the interaction of one or more stresses (anthropogenic and/or natural) and ecological effects (at one or more levels of biological organization) requires a descriptive model that meets the following criteria:

- sufficient flexibility to apply to the full range of ecosystems and anthropogenic stresses;

- adaptable, allowing improved ecological risk assessments as data and models develop over time and as experience is gained following an initial environmental decision;

- provides for a diversity of ecological endpoints upon which decisions are based and progress is monitored;

- explicitly considers the broad range of interactions between stress characterization and ecological effects analyses, from defining the nature and scales of the problem initially, to modifying the endpoints selected for evaluation, to affecting the stress-response and recovery relationships; and

- produces a synthesis output, derived from a suite of quantitative and qualitative methodologies, that reflects probabilistically the range of stress-response relationships for each endpoint and that can be used by the decision-maker along with analyses of societal factors.

At the Miami workshop, it was decided that meeting these criteria in light of the ecological realities discussed above would require the development of a "road map" that relied heavily upon scientific judgment and expertise. Ideally, ecological risk assessment guidelines developed by EPA should provide:

- the necessary "guidance" and "landmarks" for selecting the appropriate course through the three-dimensional ecological risk landscape ("The Cube"), which defines what is at risk and how it will be assessed; and

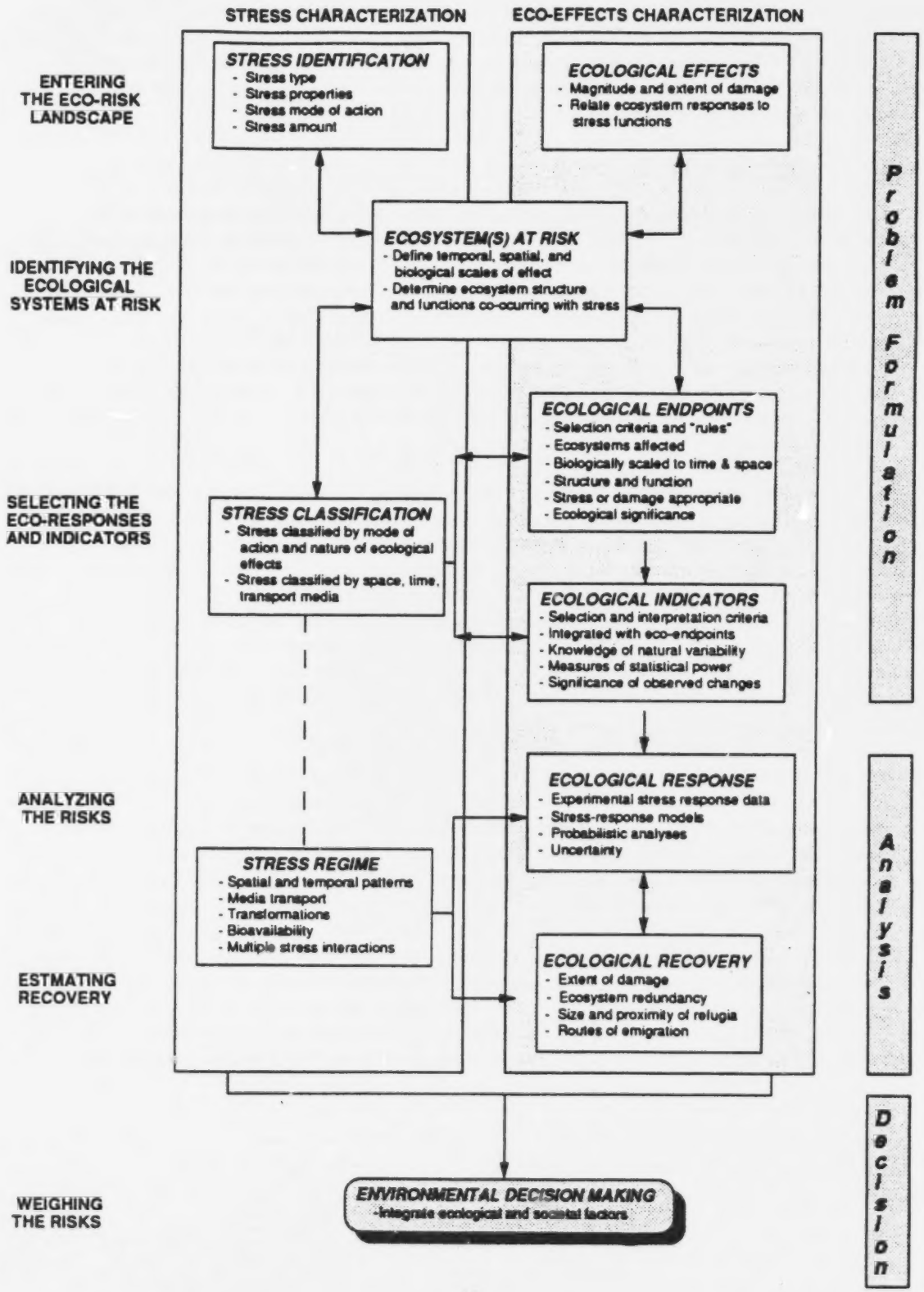
- the "appropriate technical support" in the form of a reference library for conducting site- and stress-specific ecological risk assessments.

This approach is consistent with that taken in human health risk assessments where guidance is preferable to a "cookbook" or protocol that attempts to anticipate and describe the specific steps to be taken for every situation. The resultant descriptive model of the ecological risk assessment process and the associated Guidelines Bookshelf are discussed below.

6.3. Road Map Work Group (Mark Harwell and Jack Gentile, Co-Chairs)

Beginning with the three-dimensional landscape or "Cube" as the framework within ecological risks occur and are assessed, the Miami workshop's Road Map work group identified and described the scientific issues associated with the process for conducting ecological risk assessments (figure 5). This process and associated issues are designed to integrate, through a sequence of logical steps, the two fundamental types of information in the ecological risk assessment process: ecological effects characterization and stress regime (exposure) characterization. The process is divided into two phases: "problem formulation" and "analysis." The problem formulation phase describes the entry point into the ecological risk landscape, identification of the ecosystems at risk, and the appropriate ecological endpoints by which to assess the risks. In the analysis phase, stress-effects relationships are

Figure 5. Scientific Issues in Ecological Risk Assessment



determined and compared to actual stress scenarios co-occurring in the environment to estimate the potential ecological risks. The ecological significance of the effects and the potential for recovery also were discussed.[2] The third phase of the process is environmental decision-making. This phase is actually outside the scope of the actual risk assessment, but is identified and highlighted as being of critical importance to the interpretation and use of the risk assessment results.

6.3.1. Problem Formulation

A fundamental difference between human health and ecological risk assessments is the question of defining "what is at risk?" EPA's extensive experience with specific risk issues in human health has provided a sound basis for defining the scope and subject matter for human health risk assessment guidelines. The selection endpoints for human health risk assessments (e.g., cancer and developmental toxicology) resulted from the recognized public health and regulatory importance and extensive discussions over a period of several years. In contrast, discussions regarding the selection of ecological endpoints for ecological risk assessment have begun only recently and are confounded by the lack of specific legislative and regulatory guidance. The importance of defining the "subject" of ecological risk assessments was emphasized at the recent CRAM workshop and has been a consistent theme in several EPA-sponsored workshops.

The Miami workshop identified the need for an atlas or "road map" to direct the risk assessor through the three-dimensional matrix of organizing variables ("The Cube") in order to determine "what ecosystem(s) is at risk" and "how the risks will be measured." The atlas concept was chosen because it is a readily understood metaphor that accurately describes the process of walking through the three-dimensional matrix. The primary function of the atlas is to define the ecosystems at risk, make an initial determination of the ecologically important characteristics and patterns of the stress, and determine the most appropriate ecological endpoints for assessing the risks to the ecosystem. The atlas provides the rationale and road map for integrating information on the three organizing principles comprising the "Cube," which provides the foundation for the detailed risk analysis.

The purpose of the initial steps in the problem-formulation stage is to provide guidance to the risk assessor on defining the spatial, temporal, and biological scope of the risk assessment. The initial point-of-entry into the process is problem-determined, either dealing with a stress-specific problem (e.g., decision to allow production of a new chemical or projecting the effects from global climate change on ecosystems) or dealing with an observed ecological effect (e.g., visible damage to trees in a forest, or large-scale die-off of seagrass). The former will require primarily prospective analyses (inductive); the latter will require primarily retrospective (deductive) analyses.

The second step in problem formulation is identifying the range of ecosystems that are at risk from the stress. If the problem is stress-driven, sufficient information about the stress will be needed at this stage to help define the ecosystems at risk. This information includes knowledge of the nature and properties of the stress, the spatial and temporal scale of the stress, and the intensity of the stress. If the problem is ecological effects-driven, then observed damage will be used to determine the

---

[2]Although not treated explicitly by the Road Map work group, elements of "risk characterization," which is the integration of stress and ecosystem-response information and its ecological significance, are implicit in both the analysis and decision-making phases.

ecosystems at risk directly and, by extrapolation, the ecosystems for which no observed damage occurs at present but which also may be at risk.

In addition to determining the different types of ecosystems that are at risk, this second step of problem formulation defines the spatial extent of the ecosystem(s) co-occurring with the stress; focuses attention on the components of each at-risk ecosystem that may be directly or indirectly affected by the stress; and determines the organizational scales that must be addressed (e.g., if consideration of population-level effects will suffice or if ecosystem-level processes also must be evaluated). An explicit part of this determination is to consider both structural and functional aspects of each at-risk ecosystem in the context of potential direct or indirect effects from the stress.

The third step of the problem formulation provides criteria and guidance to the risk assessor on selecting which ecological endpoints are most appropriate for evaluating the effects to the at-risk ecosystems, where "ecological endpoint" is defined to be the specific ecological properties of concern. This process is necessary because the potential number and variety of ecosystem properties that could be affected by a human activity are virtually unlimited. Thus, for each ecosystem type at risk, the risk assessor must consider the specific properties of the ecosystem that, if sufficiently altered, would constitute a change in the ecosystem that is of ecological or societal importance.

Ecological endpoints may be structural (e.g., community diversity) or functional (e.g., rates of primary production). The endpoint should be relevant, having either ecological importance (e.g., keystone species, ecologically important processes) or societal (e.g., economically important, endangered, or aesthetic species) importance. This relevance may be either direct (e.g., viability of a marine mammal species) or indirect (e.g., the food base for that species). Selection of the ecological endpoint in part is a function of the nature of the stress; i.e., some properties of the ecosystem may be known to be vulnerable to one stress but not to another. Other criteria for selecting endpoints will be developed in the ecological risk assessment guidelines, such as: natural variability of the endpoint; comparability with other ecological risk assessments (e.g., using some endpoints in common with different systems or different stresses); requirements of particular legislation or regulations; and availability of data, models, and knowledge about the specific endpoint that can be used for assessment. In any event, once the stress is known and the at-risk ecosystems are determined, there must be a concerted effort to identify all aspects of those ecosystems that would be appropriate properties upon which to evaluate the health of the ecosystem in the context of the stresses at hand. Ideally, a suite of ecological endpoints will be selected to ensure the full range of values about the ecosystem are evaluated.

The fourth and final step in the problem formulation stage is selection of "ecological indicators" defined to be the specific properties of ecosystems that are measured or monitored to reflect on the state or the change of state of the ecological endpoints. Each selected endpoint should have one or more associated indicators. These indicators may be the endpoint itself (e.g., numbers of individuals in an endangered species population) or may relate to the endpoint directly (e.g., number of eggs produced per nesting pair of birds) or indirectly (e.g., area of wetlands in a region available for nesting habitat). Criteria proposed for selecting ecological indicators include:

- signal-to-noise ratio;
- frequency of false-positive and false-negative indications of an ecological effect;

- rapidity of indicator response (e.g., for early-warning indicator) versus degree of stress-specificity (e.g., diagnostic indication of a particular stress);
- statistical power (i.e., how much data would be required to demonstrate an effect);
- ease or economy of measurement;
- availability of historical data bases; and
- comparability across ecological systems or environmental problems.

As was the case with ecological endpoints, the selection of indicators also is stress-dependent. The stress-classification process conducted to help identify the at-risk ecosystems and their ecological endpoints will directly influence the selection of the suite of indicators.

6.3.2. Response-Recovery Analysis

The response-recovery analysis stage integrates both the stress-characterization components and the ecological-effects characterization components to provide a qualitative or quantitative characterization of the ecological risks. At this stage, the full set of stress characterization issues must be addressed, including such issues as:

- the nature of the stress (i.e., physical, chemical, or biological or xenobiotic versus alterations in naturally occurring stresses);
- the stress' spatial and temporal scales, including factors such as the spatial distribution of stress-intensity levels, and the frequency and duration of the stress;
- transformations of the stress in the environment (e.g., chemical modifications from physicochemical or biological processes);
- bioavailability of the stress (e.g., biouptake of chemicals, differential exposure of different parts of an organism);
- interactions with the physical environment (e.g., co-occurrence with periods of high temperature and atmospheric inversions); and
- interactions with other stresses (e.g., synergism between acid precipitation and ozone exposure).

The analysis stage also includes detailed ecological stress-response assessments. This may involve extrapolations among endpoints (e.g., extrapolations from laboratory data to the field) or extrapolations across biological scales (e.g., from organisms to population, community, or higher levels of organization). Such assessments may utilize:

- mathematical models of direct or indirect effects on ecological components;
- the evaluation of analogs, such as paleoecological analogs of climate change;

- the experiences gained from different ecosystems of similar type for similar stresses;
- structural activity relationships of chemicals;
- new experiments to be conducted in the laboratory on physiological processes;
- microcosms, mesocosms, or whole-ecosystem manipulations.

The interpretation of available data will fundamentally rely on expert judgment; initially expert judgment may be the only methodology available. Assessments may be quantitative and probabilistic, if adequate models and data are available. Whatever methodologies are available for quantitatively or qualitatively evaluating the ecological endpoint responses for each at-risk ecosystem for the specific stress regime(s) will be synthesized to assess the overall ecological effects from the stress. While the goal is to have a predictive capability for stress-response relationships with low uncertainty, the process allows for ecological risk assessments to proceed and to provide substantive guidance to the decision-maker even in the presence of significant uncertainties. The uncertainties that exist in all stages of the assessment must be made explicit and carried along (propagated) in the final analyses.

The scientific issues and process, as described in figure 5, explicitly consider the importance of characterizing the stress regime as opposed to merely preparing a hazard assessment from hypothetical levels of the stress. The final output from these stress-response analyses is a graphical representation of how the ecological endpoints would respond to ranges of the stress. Since the purpose of the stress-response analysis is to prepare a probabilistic evaluation of a range of stress-response relationships, evaluations will be required for different intensities, durations, and frequencies of the stress.

The methods used in the stress-response analyses are intended to be adaptive; that is, as new methodologies are developed with improved predictive capabilities, they can be substituted into the risk assessment process. Further, once a decision is made, monitoring of selected ecological indicators can be instituted to determine the degree of coherence between the observed responses and those predicted from the risk assessment. Review of this information may suggest the need to revise the initial management decisions.

The ecological recovery characterization provides information on whether a stress-induced effect on an ecosystem is reversible or is irreversible, which may be particularly important to both the scientist and the decision-maker. Ecological recovery can be characterized in terms of:

- the rate at which ecological endpoints recover once a stress is removed;
- how much recovery might ensue from reductions in the level or frequency of the stress; and
- the degree of recovery feasible or required for particular uses.

The recovery of ecological systems is related to:

- the characteristics of the ecosystem;

- the nature of the stress;
- previous ecosystem experience with the particular type of stress;
- the intensity of the initial effect and its spatial extent;
- the potential sources of propagules for replacing species;
- how much the effects cut across functionally redundant components of the ecosystem;
- intrinsic time-lags in the ecosystem; and
- many other factors.

The methodologies applied to the recovery analyses range from sole reliance on expert judgment to use of analogs, simple mathematical models, and detailed process-oriented simulation models. The approach used to characterize ecological recovery, like stress-response analysis, is to be adaptive and flexible, require the tracking of uncertainties, and, when possible, will produce probabilistic outputs for the decision-maker. Finally, the output from the risk assessment becomes input to the environmental decision-making process, which also incorporates factors such as environmental policy, regulatory statutes, economics, and societal issues.

6.3.3. Environmental Decision-Making

The workshop participants recommended that guidance be developed for environmental mangers on the use of ecological risk assessment information. Although the topic is outside the purview of ecological risk assessment, environmental decision-making does interface with the risk assessment process. Information applicable to environmental decision-making could be used to develop guidance on interpreting information produced by the ecological risk assessment process; on establishing levels of ecological significance (versus statistical significance) for changes in each type of ecological endpoint; and on merging information on non-ecological issues, such as economic or other societal considerations. This section also could include guidance to the risk assessor on communicating the results of the risk assessment process.[3] Thus, there appeared to be a need for management guidelines for risk-based decision-making analogous to the guidelines being developed for ecological risk assessment.

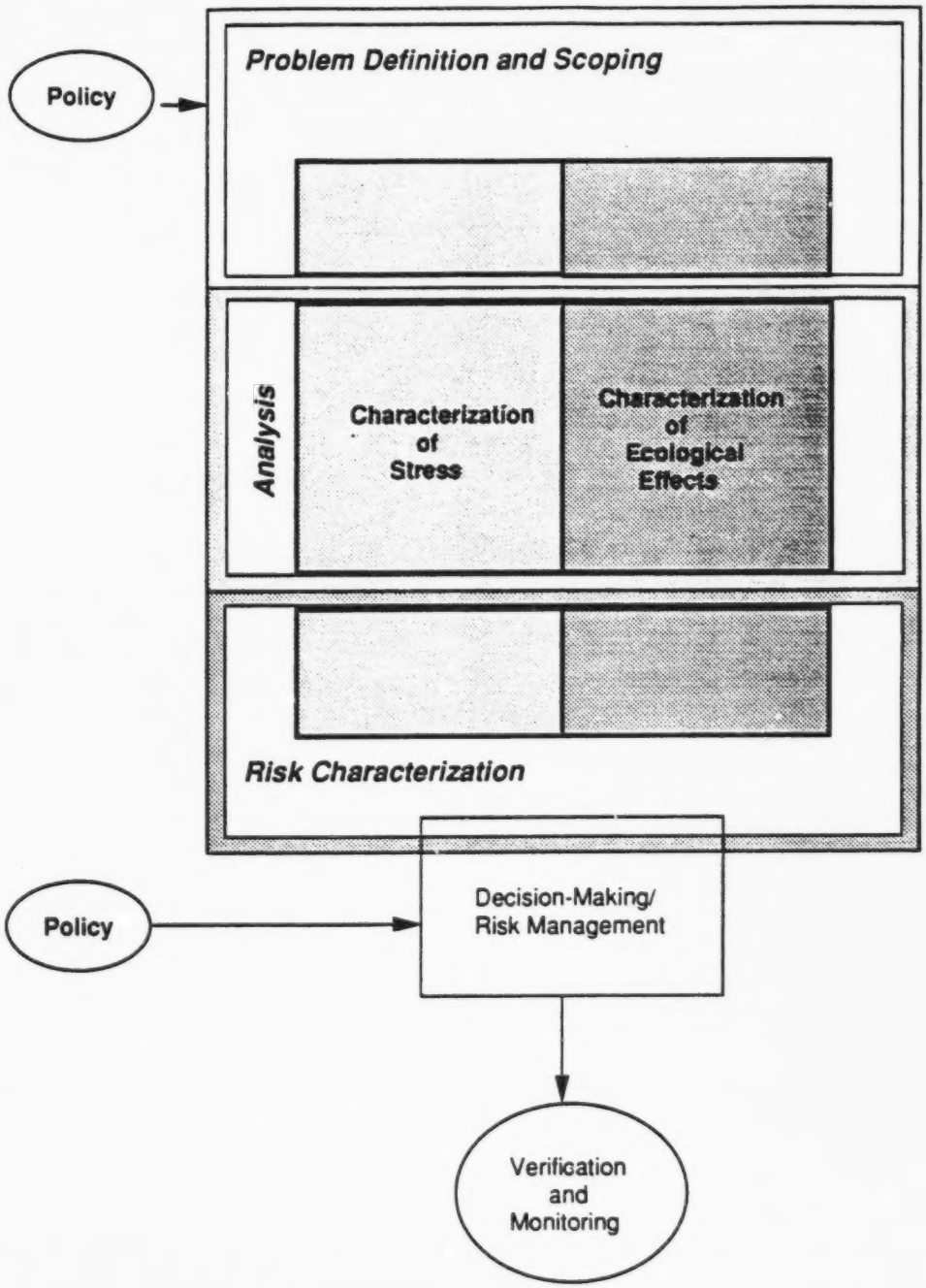
6.3.4. Relationship to the Ecological Risk Framework

The description of the ecological risk assessment process that emerged from the Road Map work group was presented and discussed at the peer review of EPA's "Framework for Ecological Risk Assessment" (May 14-16, 1991) (U.S. EPA, in press-b). It is clear that the framework for ecological risk assessment recommended by the peer-review panel (figure 6) is philosophically and conceptually similar to the process discussed above and illustrated in figure 5. In addition it was recognized that

---

[3]The concept and issues that constitute risk characterization, though not explicitly identified in figure 5, are covered in part in the analysis and environmental decision-making steps.

Figure 6. Proposed Framework for Ecological Risk Assessment



additional detail would be needed for each of the framework components in order to provide meaningful guidance. The scientific issues identified at the Miami workshop contributed substantively to the development of the ecological risk framework and are embodied within the peer-review panel's recommendations to EPA. One apparent difference between the ecological risk framework and the ecological risk process described in this workshop report relates to the treatment of risk characterization. Although these two workshops had different objectives, the philosophy, concepts, and principles developed at both workshops are consistent, and only minor differences in terminology remain to be resolved. The development of ecological risk guidelines is an evolving process, one that will continually seek to incorporate new ideas and reflect the ever-changing state-of-the-science. While this may result in modifications of terminology and specific details, the fundamental philosophy and concepts are expected to remain unchanged.

6.4. Proposed Future Ecological Risk Assessment Guidelines

6.4.1. Background

The Guidelines Bookshelf is a proposed set of guidance volumes to be produced by EPA in its ecological risk assessment guidelines development process.[4] The guidance volumes in the series should not consist of "cookbooks," i.e., case-specific guidelines written for particular types of environmental problems or for particular types of ecological systems. Rather, the volumes should constitute a reference library that the risk assessor can use in conducting a particular ecological risk assessment. The recommendations from the Road Map work group are that the subject matter of the guidelines Bookshelf reflect the scientific issues and the process for ecological risk assessment described in figure 5. Focusing the contents of the proposed guidelines on the risk assessment process will produce generic, broadly applicable guidance that can be easily adapted and tailored to specific ecosystem problems. Based upon this rationale, the Guidelines Bookshelf recommended by the Road Map work group includes:

I. Ecological Risk Assessment Guidelines
II. Ecological Endpoints
III. Ecological Indicators
IV. Stress Regime Characterization
V. Ecological Response Characterization
VI. Ecological Recovery
VII. Environmental Decision-Making
VIII. Compendium of Case-Specific Examples

---

[4]The first volume on the bookshelf will be the "Framework for Ecological Risk Assessment" which describes the ecological risk assessment principles and concepts. It was not included in this listing because it does not provide the level of detail necessary for guidance.

6.4.2. Ecological Risk Assessment Guidelines

The Ecological Risk Assessment Guidelines volume, which will evolve from an expansion of EPA's "Framework for Ecological Risk Assessment", will be the primary guidance volume on the bookshelf and will describe in detail the full spectrum of scientific issues associated with the ecological risk assessment process. This volume will describe the principles and criteria for each phase, explain the process for conducting ecological risk assessments, and, through selected hypothetical analogs, demonstrate the specific steps and processes that would be pursued for assessing the risks to specific ecosystems from particular stresses. The problem formulation phase of the Ecological Risk Assessment Guidelines will function as an "atlas" in the sense that it will describe and integrate the full landscape of organizing principles in which ecological risks occur and consequently risk assessments should be conducted. A primary function of the problem formulation phase will be to define the ecosystems at risk, make an initial determination on the ecologically important characteristics of the stress, determine the most appropriate ecological endpoints for assessing the risks to the ecosystem, and provide the foundation for the detailed risk analysis phase.

The Ecological Risk Assessment Guidelines will be generic and will focus on scientific issues and the ecological risk process, rather than on details of specific applications. However, the Miami and other workshops have stressed the importance of having case studies or hypothetical analogs to illustrate how the guidelines are to be applied and how they will function. It is recommended, therefore, that this initial volume have a sufficient number of examples to illustrate the scope and variety of applications.

However, providing sufficient level of detail on all the important scientific issues for a subject as complex as ecological risk may not be feasible in a single volume. The following volumes will provide the level of detail necessary for ecological risk guidance and should be developed in parallel with the generic guidance described above.

6.4.3. Ecological Endpoints

The Ecological Endpoints volume will detail the principles and issues associated with ecological endpoints, including the specific criteria that should be applied to selecting the suite of ecological endpoints germane to a particular environmental problem and for a particular ecological system type. The endpoints volume will identify criteria for selecting endpoints that might be used, given the diversity of ecosystems and stresses of concern to EPA, and the bases for selecting the particular subset of endpoints appropriate to the problem at hand.

6.4.4. Ecological Indicators

Similarly, the Ecological Indicators volume will detail the principles, issues, and criteria for selecting the specific indicators to be measured for each ecological endpoint used in the ecological risk assessment. Perhaps these latter two volumes (endpoints and indicators) could be combined into a single volume. Also, within these two volumes will be a discussion of how to evaluate the ecological significance of changes in endpoints (and indicators) as the initial examination of statistical power, uncertainties, and natural variability issues.

6.4.5. Stress Regime Characterization

The Stress Regime Characterization guidance will discuss the complete set of issues associated with understanding the characteristics of the stress in its entirety (i.e., the nature of the stress, its spatial extent, intensity, duration, frequency, interactions). In a sense, this volume is analogous to an exposure assessment volume, but will be much broader in that nonchemical stresses will be equally important and will require different kinds of attention from the stress characterization (exposure) issues for chemicals in the environment.

6.4.6. Ecological Response Characterization

The Ecological Response Characterization volume will describe the various methodologies for evaluating stress-ecological response relationships, including: expert judgment; various methods for qualitative evaluations; extrapolations from laboratory, microcosm, or field data; and various types of quantitative, predictive models of components of ecosystems. The applicability, availability, and uncertainties for each approach, as well as guidance on when to use a particular method, will be detailed. This volume will be a key methodology document that will be updated routinely as new methods become available.

6.4.7. Ecological Recovery

The Ecological Recovery volume will likewise detail the principles, issues, and methods for addressing issues of ecological recovery upon elimination or mitigation of stress. Again, methodologies for evaluating recovery (expert judgment through predictive models) will be discussed, as will all germane issues of uncertainty. This volume also will be updated periodically as methodologies and understanding of recovery issues improve.

6.4.8. Environmental Decision-Making

Originally, the environmental decision-making volume was conceived as a separate volume that was not a part of the ecological risk assessment process per se. Instead, this volume would provide specific guidance to the decision-maker on how to interpret the information produced by the ecological risk assessment process and how to merge this information with information on economics or societal values. However, a need still remains for guidance on environmental decision-making that is specifically tailored to and developed by risk managers on how to effectively incorporate the results of risk assessments into a risk-based decision-making framework.

6.4.9. Case-Specific Compendium

Finally, a compendium of actual case-specific studies that have been conducted using the Ecological Risk Assessment Guidelines should be included as part of the bookshelf. This volume will be a "living document," frequently revised and updated with new examples of actual ecological risk assessments. Eventually, this volume will contain a sufficient number of examples so that the full range of types of ecological risk assessments that might be encountered by a risk assessor will be represented by at least one case example in this compendium. While not supplanting the overall generic approach, the case-specific compendium will illustrate, in detail, the application of the Ecological Risk Assessment Guidelines to specific ecosystems, regulatory statutes, and problem-oriented studies.

7. REFERENCES

Barnthouse, L.W.; Suter, G.W., II; Bartell, S.M.; Beauchamp, J.J.; Gardner, R.H.; Linder, E.; O'Neill, R.V.; Rosen, A.E. (1986). User's Manual for Ecological Risk Assessment. Publication No. 2679, ORNL-6251. Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN.

Harwell, M. A.; Harwell, C.C.; Weinstein, D.A.; Kelly, J.R. (1990). Characterizing ecosystem responses to stress. In: Grodzinski, W.; Cowling, E.B.; Breymeyer, A.I.; Phillips, A.S.; Auerbach, S.I.; Bartuska, A.M.; Harwell, M.A., eds. Ecological Risks: Perspectives from Poland and the United States. National Academy of Sciences Press. pp 91-115.

Kelly, J.R.; Harwell, M.A. (1989). Indicators of ecosystem response and recovery. In: Levin, S. A.; Harwell, M.A.; Kelly, J.R.; Kimball, K., eds. Ecotoxicology: Problems and Approaches. Advanced Texts in the Ecological Sciences Series. Springer-Verlag. New York, NY. pp 9-35.

Kelly, J.R.; Harwell, M.A. (1990). Indicators of ecosystem recovery. In: Yount, J.D.; Niemi, G.J., eds. Recovery of Lotic Communities and Ecosystems Following Disturbance: Theory and Application. Environmental Management 14(5):527-546.

NRC. See National Research Council.

National Research Council. (1983). Risk Assessment in the Federal Government: Managing the Process. National Research Council, National Academy Press, Washington, DC.

U.S. EPA. See U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. (1986). The Risk Assessment Guidelines of 1986. EPA/600/8-87/045, Washington, DC.

U.S. Environmental Protection Agency. (1988). Review of Ecological Risk Assessment Methods. EPA/230/10-88/041, Washington, DC.

U.S. Environmental Protection Agency. (1990). The Report of the Ecology and Welfare Subcommittee, Relative Risk Reduction Project. In: Reducing Risks: Setting Priorities and Strategies for Environmental Protection. EPA SAB-EC-90-021A, Science Advisory Board, Washington, DC.

U.S. Environmental Protection Agency. (1991). Summary Report on Issues in Ecological Risk Assessment. EPA/625/3-91/018, Risk Assessment Forum, Washington, DC.

U.S. Environmental Protection Agency. (in press-a). Peer Review Workshop Report on a Framework for Ecological Risk Assessment. EPA/630/R-92/001, Risk Assessment Forum, Washington, DC.

U.S. Environmental Protection Agency. (in press-b). Framework for Ecological Risk Assessment. EPA/630/R-92/001. Risk Assessment Forum, Washington, DC.

APPENDIX A

AGENDA

AGENDA

U.S. Environmental Protection Agency

ECOLOGICAL RISK ASSESSMENT GUIDELINES
STRATEGIC PLANNING WORKSHOP

TUESDAY, APRIL 30, 1991

8:30 a.m. - 12:15 p.m. **Opening Plenary Session: Issues and Objectives**

8:30 a.m. Welcome and Workshop Objectives
Dorothy Patton

8:50 a.m. Ecorisk Framework
William van der Schalie

9:15 a.m. Scientific Principles for Ecorisk
John Gentile

10:00 a.m. **BREAK**

10:15 a.m. - 12:15 p.m. **Ecological Hierarchy Presentation**

10:15 a.m. Organisms/Population
Steven Bartell

11:00 a.m. Con munities
Ann Bartuska

11:30 a.m. Ecosystems
David Weinstein

12:00 p.m. Wrap-up/Charge to Ecological Hierarchy Work Groups
Mark Harwell

12:15 p.m. **LUNCH**

1:30 p.m. - 5:00 p.m. **Ecological Hierarchy Work Groups**

1:30 p.m. Work Group Sessions
Steven Bartell, Ann Bartuska, and David Weinstein

TUESDAY, APRIL 30, 1991 (cont.)

3:10 p.m.	**BREAK**
3:30 p.m.	Work Group Sessions (cont.)
5:00 p.m.	**ADJOURN**
5:00 p.m.	RSMAS Reception - Smith Commons

WEDNESDAY, MAY 1, 1991

8:30 a.m. - 10:00 a.m. **Plenary: Reports and Discussion**

8:30 a.m.	Welcome to RSMAS *Otis Brown, Associate Dean for Research*
8:40 a.m.	Organisms/Population *Steven Bartell*
9:00 a.m.	Communities *Ann Bartuska*
9:30 a.m.	Ecosystems *David Weinstein*
10:00 a.m.	Wrap-up/Charge to Ecosystem Work Groups *Mark Harwell*
10:10 a.m.	**BREAK**

10:30 a.m. - 5:00 p.m. **Scientific Feasibility Work Groups**

10:30 a.m.	Work Group Sessions by Ecosystems Type *Robert Hugget and William Smith*
12:15 p.m.	**LUNCH**
1:30 p.m.	Work Group Sessions (cont.) Evaluate Scientific Feasibility
3:30 p.m.	**BREAK**

WEDNESDAY, MAY 1, 1991 (cont.)

4:00 p.m. Work Group Sessions (cont.)
Prioritize Guidelines and Prepare Recommendations

4:30 p.m. **ADJOURN**

THURSDAY, MAY 2, 1991

8:00 a.m. - 9:45 a.m. Scientific Feasibility Work Groups

8:00 a.m. Work Group Sessions (cont.)
Prioritize Guidelines and Prepare Recommendations

9:45 a.m. **BREAK**

10:00 a.m. - 12:00 p.m. Closing Plenary: Candidate Guidelines

10:00 a.m. Aquatic Guidance
Robert Huggett

10:15 a.m. Wrap-up

10:30 a.m. Terrestrial Guidance
William Smith

10:45 a.m. Wrap-up

11:00 a.m. Workshop Recommendations
Mark Harwell

12:00 p.m. **ADJOURN**

APPENDIX B

LIST OF PARTICIPANTS

LIST OF PARTICIPANTS

U.S. Environmental Protection Agency

ECOLOGICAL RISK ASSESSMENT GUIDELINES
STRATEGIC PLANNING WORKSHOP

Lawrence Barnthouse
Oak Ridge National Laboratory
Oak Ridge, TN

Steven Bartell
Oak Ridge National Laboratory
Oak Ridge, TN

Ann Bartuska
U.S. Department of Agriculture
Forest Service
Ashville, NC

Steven Bradbury
U.S. Environmental Protection Agency
Environmental Research Laboratory - Duluth
Duluth, MN

Hal Caswell
Woods Hole Oceanographic Institute
Woods Hole, MA

David Charters
U.S. Environmental Protection Agency
Emergency Response Team
Edison, NJ

William Cooper
Michigan State University
East Lansing, MI

Michael Coughenour
Colorado State University
Fort Collins, CO

Wendell Cropper
University of Florida
Gainesville, FL

Thomas Duke
Technical Resources Institute
Gulf Breeze, FL

Anne Fairbrother
U.S. Environmental Protection Agency
Corvallis, OR

Jeffrey Frithsen
Versar, Inc.
Columbia, MD

Jack Gentile
U.S. Environmental Protection Agency
Environmental Research Laboratory
Narragansett, RI

Herbert Grover
Environmental Scientist
Sandia Park, NM

Thomas Hallam
University of Tennessee
Department of Mathematics
Knoxville, TN

Mark Harwell
University of Miami
Rosenstiel School of Marine &
Atmospheric Science
Miami, FL

Robert Huggett
Virginia Institute of Marine Sciences
School of Marine Sciences
College of William and Mary
Gloucester Point, VA

Erich Hyatt
U.S. Environmental Protection Agency
EMAP Integration & Assessment
Research Triangle Park, NC

John Kelly
Battelle Ocean Science
Duxbury, MA

James Kremer
University of Southern California
Department of Biological Sciences
Los Angeles, CA

David Mauriello
U.S. Environmental Protection Agency
Office of Toxic Substances
Washington, DC

Foster Mayer
U.S. Environmental Protection Agency
Environmental Research Laboratory
Gulf Breeze, FL

Anne McElroy
University of Massachusetts
Environmental Science Program
Boston, MA

Steven Paulsen
University of Nevada
Northrop Facility
c/o U.S. Environmental Protection Agency
Corvallis, OR

Eric Preston
U.S. Environmental Protection Agency
Corvallis, OR

John Schalles
Creighton University
Department of Biology
Omaha, NE

Michael Slimak
U.S. Environmental Protection Agency
Office of Environmental Processes &
Effects Research
Washington, DC

William Smith
Yale University
School of Forestry &
Environmental Studies
New Haven, CT

Samuel Snedaker
University of Miami
Rosenstiel School of Marine &
Atmospheric Science
Miami, FL

Kent Thornton
FTN Associates, Ltd.
Little Rock, AR

Thomas Waddell
U.S. Environmental Protection Agency
Athens, GA

Richard Weigert
University of Georgia
Department of Zoology
Athens, GA

David Weinstein
Boyce Thompson Institute
Ithaca, NY

APPENDIX C

LIST OF OBSERVERS

U.S. Environmental Protection Agency

ECOLOGICAL RISK ASSESSMENT GUIDELINES:
STRATEGIC PLANNING REPORT WORKSHOP

University of Miami
Miami, FL

April 30-May 2, 1991

LIST OF OBSERVERS

Janet Burris
Biologist
U.S. Environmental Protection Agency
Washington, DC

William Easton
Miami, FL

John Festa
American Paper Institute
Washington, DC

Chris Harwell
University of Miami
Rosenstiel School of Marine &
Atmospheric Science
Miami, FL

Normal Kowal
U.S. Environmental Protection Agency
ECAO
Cincinnati, OH

Ronald Landy
U.S. Environmental Protection Agency
Office of Research and Development
Washington, DC

Steve Light
Policy Director
South Florida Water Management District
West Palm Beach, FL

Charles Menzie
Menzie Cura & Associates, Inc.
Chelmsford, MA

Dorothy Patton
U.S. Environmental Protection Agency
Risk Assessment Forum
Washington, DC

J. Brad Peebles
Principal Specialist
Florida Power & Light
West Palm Beach, FL

Susan Norton
U.S. Environmental Protection Agency
Office of Health & Environmental
Assessment
Washington, DC

Denice Shaw
U.S. Environmental Protection Agency
Environmental Scientist
Las Vegas, NV

William van der Schalie
U.S. Environmental Protection Agency
Risk Assessment Forum
Washington, DC

William Wood
U.S. Environmental Protection Agency
Risk Assessment Forum
Washington, DC